JOURNAL

of the

AIR POLLUTION CONTROL ASSOCIATION

Founded 1907

November 1959
Vol. 9, No. 3

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(See page 156)

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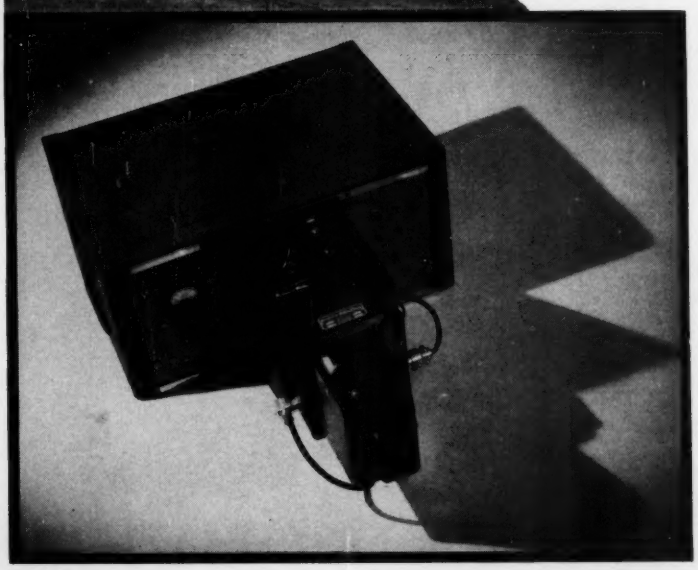

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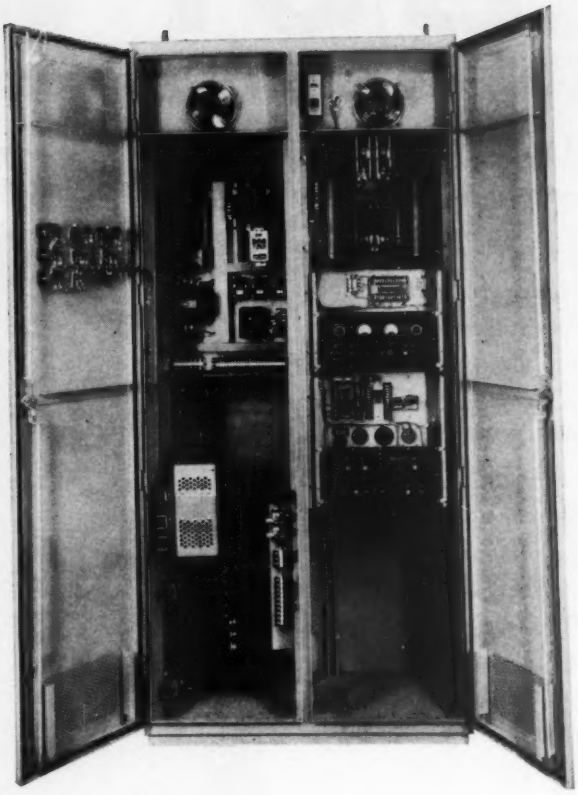

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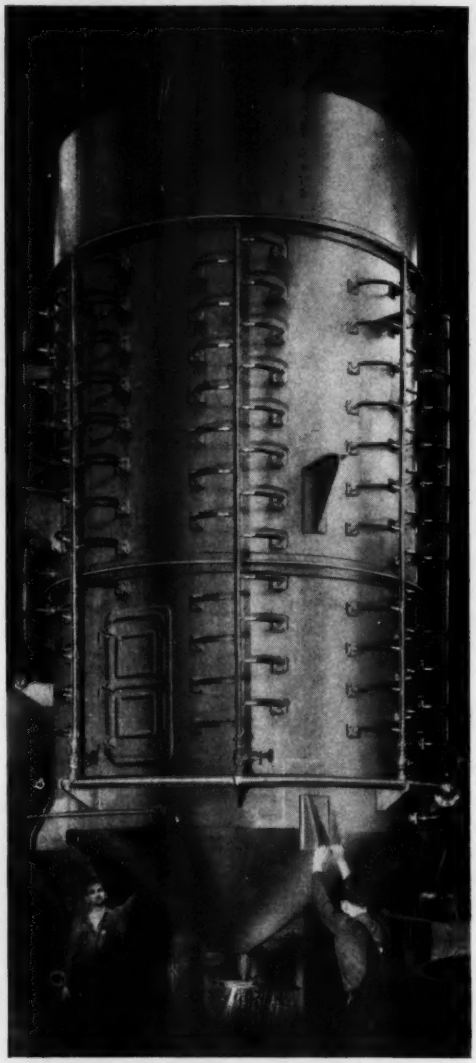

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FOUNDED 1907

JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION

(Formerly "Air Repair")

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CONTENTS

NOVEMBER 1959 VOL. 9, NO. 3

Epidemiological Aspects of Air Pollution
John R. Goldsmith and Lester Breslow 129

Graduate Education for Air Pollution Control Personnel
E. R. Hendrickson 133

Particulate Pollutants in the Air of the United States
Charles E. Zimmer, Elbert C. Tabor and Arthur C. Stern 136

Comments on "Particulate Pollutants in the Air of the United States"
Walter A. Quebedeaux, Jr. 144

Technical Manual on Single Retort Underfeed Stokers
APCA Technical Co-ordinating Committee TA-6 145

Critique of the Article: "Effectiveness of Odor Counter-actants for the Treatment of Stack Gases"
Amos Turk 157

An Automatic Atmospheric Fluoride Analyzer
Donald F. Adams, Robert K. Koppe and Homer J. Dana 160

Abstracts of Legal Decisions Relating to Air Pollution
Legal Committee 169

Classified 168

Index to Advertisers 159

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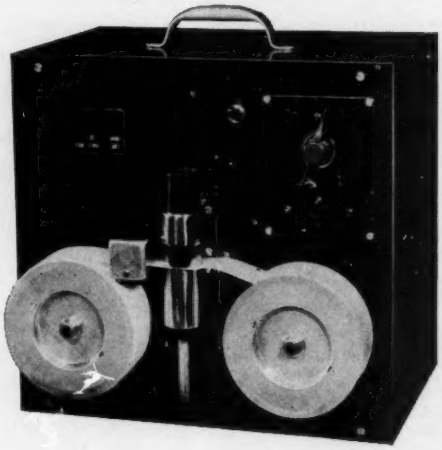

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Epidemiological ASPECTS OF *Air Pollution**

JOHN R. GOLDSMITH, M.D. and **LESTER BRESLOW,** M.D., Bureau of Chronic Diseases, California State Department Public Health.

Epidemiology of acute diseases has led to effective prevention of such diseases as cholera and smallpox. These achievements allow us to live together in great metropolitan complexes like Los Angeles, free from the very great toll formerly taken by premature death.

Life in a modern city brings with it new health challenges. These new health problems, including mental health, alcoholism, chronic disease, air pollution, and exposure to the by-products of newly harnessed energy forms, such as radiation, have brought forth a new emphasis in public health, and a new concern with air, comfort, and enjoyment of our longer life span. In these areas as in traditional ones also, epidemiology is the basic fact-finding tool of public health.

If it were feasible to expose people experimentally to all kinds and concentrations of air pollutants, there would be less need for air pollution epidemiology. This is not possible, so investigation must be made of naturally occurring human exposures to air pollution. Natural air pollution exposures are the raw data of the air pollution epidemiologist; the meticulous classification, analysis, and comparison of these data is his operating procedure. Finally air pollution epidemiology is concerned with groups of persons, and their reaction to air pollution exposures; it is not so greatly concerned with reactions of single individuals.

Just as epidemiology led to methods for control of water-borne disease before bacteriology permitted the accurate diagnosis of them, so it is hoped that epidemiology may assist in the control of the health effects of air pollution even before it is possible to diagnose a disease caused by air pollution.

The studies to be described are concerned with how air pollutants damage the health of groups of people. Several basic problems recur in all of these studies, the accurate description of the groups of people to be studied, the definition and measurement of air pollution, the detection and measurement of effects possibly related to air pollution and the clarification of any relationship between these effects and air pollution.

The importance of air to health may easily be overlooked. Each day we bring into our lungs for equilibration with the blood, some 30 pounds of air, compared with our daily exchange of five pounds of water and less than four of food. Man can survive about five weeks without food, about five days without water, but only about five minutes without air.

A start was made in California by reviewing what was known about air pollution effects and listing the types of effects which could be looked for, measured, and hopefully prevented. Five potentially measurable health effects of air pollution are now of concern:

Air pollution may cause acute sickness and death such as occurred in the Muese Valley, at Donora, and during the several London episodes.

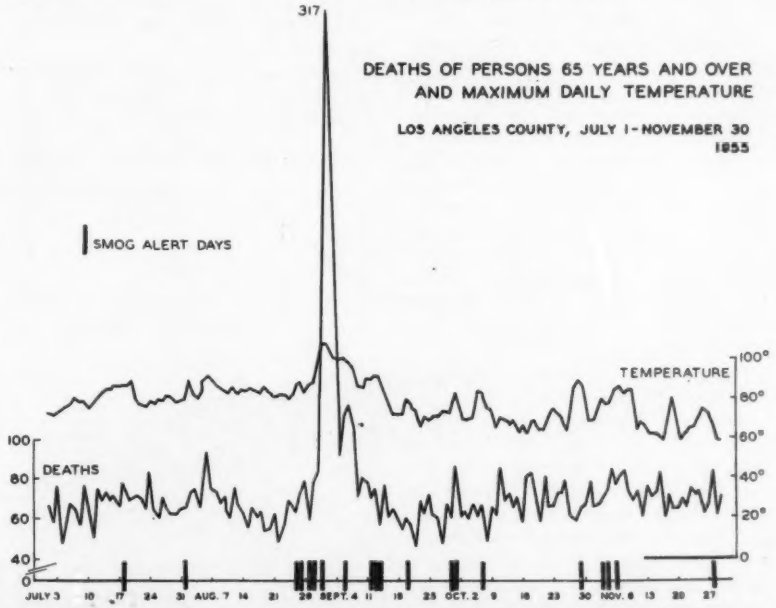
Air pollution may cause or aggravate chronic diseases such as chronic bronchitis, emphysema, or lung cancer.

Air pollution may cause interference with important bodily functions such as the exchange of gases in the lung or gas transport by the blood.

Air pollution may cause adverse bodily symptoms such as eye irritation and difficulty in breathing.

Air pollution, because it is unpleasant in many ways, may cause groups of persons to be dissatisfied with or leave their places of residence or work.

In studies on the health effects of air pollution in California data has been collected about each of these possible effects, acute sickness or death, chronic or insidious disease, interference with bodily function, production of adverse symptoms, and instability of residential or work communities.



Source: U. S. Weather Bureau. State of California, Department of Public Health, Death Records.

Fig. 1

* Presented at the Air Pollution Control Association Meeting, June 22, 1959, Statler-Hilton Hotel, Los Angeles, California.

The work commenced in the fall of 1954 at which time a series of air pollution episodes in Los Angeles led people to ask whether "can this air pollution kill people?" That summer and fall three distinct smog episodes occurred. The daily number of deaths among persons over 65 did not appear to fluctuate in response to these episodes, nor did the total daily deaths, or the deaths due to cardiac or respiratory causes.

In late August and early September, 1955 there was a period of very high temperature both preceded and followed by smog. During the high temperature, the number of deaths rose, but with falling temperatures the number of deaths dropped despite continued high air pollution levels (Fig. 1).

In a further attempt to assess the immediate mortality effect of air pollution, the California State Department of Public Health has been obtaining since 1954 reports on daily deaths and transfers to hospitals among the 4000 or so residents of nursing homes in Los Angeles with 25 or more beds. These persons are for the most part elderly and often in frail health. Except for the heat wave mentioned above, there has been no increase in mortality from this group which could be associated with air pollution (Fig. 2). In consultation with biostatistical experts we are working out methods for the separation of the effects of high temperature from the possible effects of air pollution.

During the smog episodes in 1954 a probability sample of Californians were being interviewed about their health. There was no evidence that they experienced more sicknesses or hospitalizations during the smog episodes.

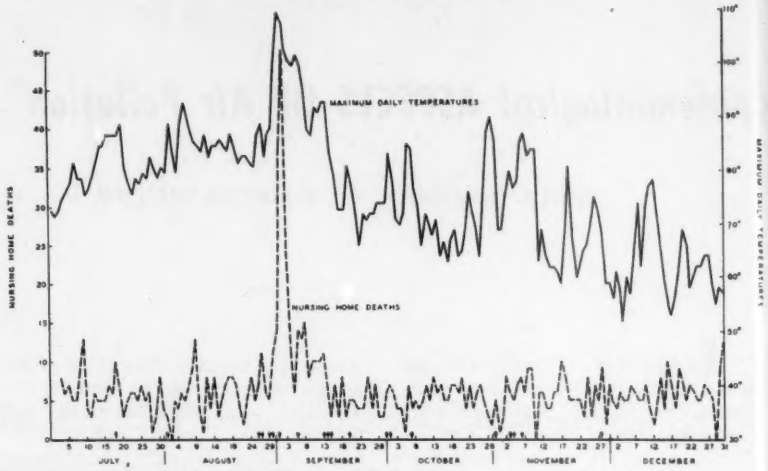
Acting on reports of physicians that patients with asthma were adversely affected by air pollution, our staff undertook a study of the possible relation of asthma attacks to air pollution levels in Pasadena in the fall of 1956. Investigation of 137 private patients of a cooperating group of physicians for a period of 10 weeks, disclosed a very low positive association between asthma attacks and air pollution levels.

Increasing frequency of two chronic diseases of the lung, lung cancer and emphysema of the lung, leads to questions concerning the possible effect on them of air pollution.

Lung cancer has a clear-cut causal relationship with cigarette smoking. Less well known is the fact that nationwide the disease is more frequent in urban counties than in rural ones (Fig. 3). Urban air pollution provides a possible explanation. There are also a number of occupations which appear to be associated with lung cancer (Fig. 4).

In California there are no important differences in lung cancer rates between

NURSING HOME DEATHS, MAXIMUM DAILY TEMPERATURES AND SMOG ALERT DAYS
LOS ANGELES COUNTY, CALIFORNIA, JULY, 1955 THROUGH DECEMBER, 1955



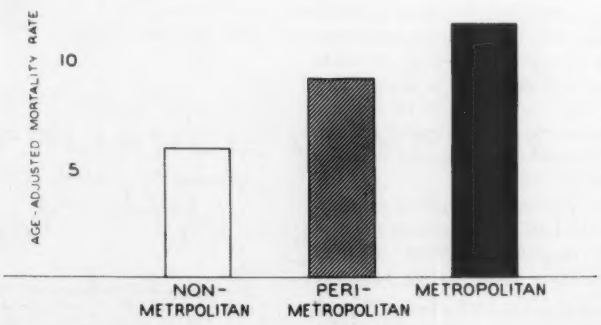
† = Days of official alerts (ozone 0.50 ppm or higher).
Source: State of California, Department of Public Health.

Fig. 2

cities and rural areas, but we feel this may be due to the fact that so many Californians have migrated here from other states and from one part of the state to another. With the support of the American Cancer Society and the co-operation of the California Department of the American Legion, data on present and past residence, occupation, and smoking have been obtained on about 75,000 Legionnaires and 50,000 of their wives. A search is planned among the death certificates for all persons dying of lung cancer in California over the next five to 10 years to see how many people in various portions of this study group die of the disease. Thus one may find out what effect living in air polluted areas of the state may have on the lung cancer death rate.

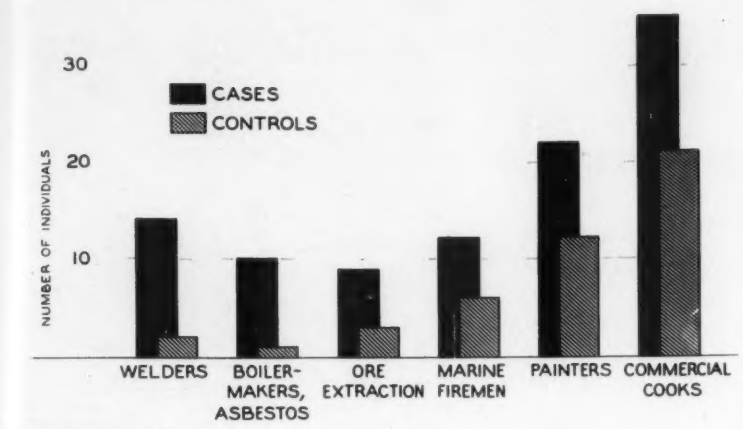
In the case of pulmonary emphysema the death rate in California increased fourfold in the period 1950 to 1957 (Fig. 5). There are several possible explanations for this. Physicians may be giving this diagnosis on death certificates rather than asthma or bronchitis, which are related disorders. Figure 5 suggests that this is not the case since there is no long-term fall in asthma and bronchitis. The people who died may have come here because they had the disease and wanted to live in a warm, dry, climate. They may be persons who survived other formerly fatal conditions such as tuberculosis or pneumonia. These questions are now being explored by interviewing both physicians who cared for patients dying of these sicknesses, and the next-of-kin of the patients. It is necessary to know how the physician chose the diagnosis, what previous illnesses, occupations and residences the person had, how much smoking they did, and for those who moved here, whether they moved for

THE ASSOCIATION OF LUNG CANCER WITH URBANIZATION OF COUNTY OF RESIDENCE



Source: Manos

Fig. 3



Source: Breslow, et al.

Fig. 4

health or medical reasons. This information may shed some light on the possible relationship of air pollution to the epidemiology of pulmonary emphysema. It is important to state here, too, that urban-rural differences exist nationwide for emphysema but do not so exist in California.

Only recently has exploration begun in the study of the possible epidemiological use of measurements of lung function as they relate to the air pollution problem. It is assumed that irritating air pollutants on being breathed will alter the airways in such a way as to increase the resistance to airflow. Several instruments for estimating maximal rate of airflow are being compared in the effort to measure this property of lung function.

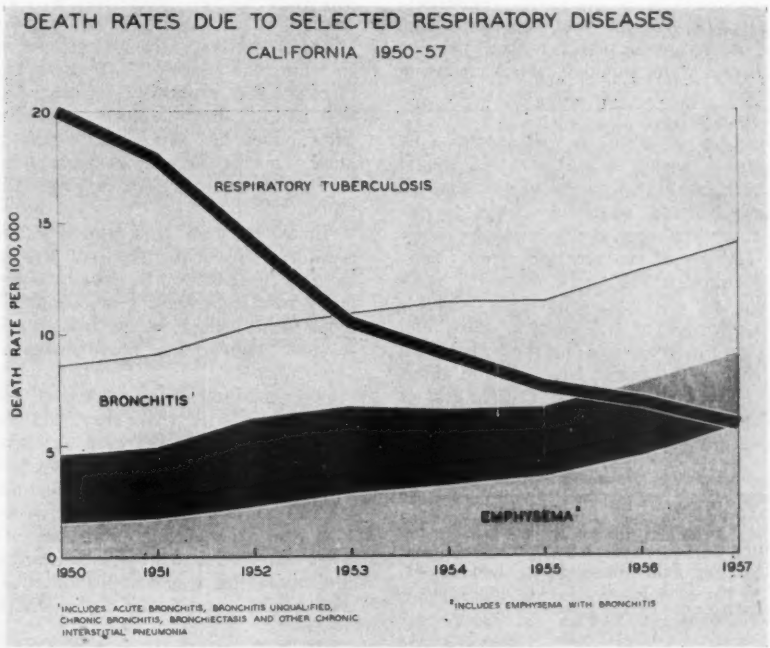
Over a period of days we tested a large number of persons once, also obtaining the age, sex, smoking, and occupational history necessary for their classification. For analysis of such a study it is necessary to assume that, but for air pollution exposure, all persons of same age, sex, smoking and occupational groups should have the same test results. The study was undertaken last summer (1958) in Vernon, an industrial area in central Los Angeles County, at the time of an x-ray survey. About 6500 persons were tested, during a time which was fixed in advance. Unfortunately there was little air pollution during the days our equipment and team were available, the maximum value being 0.18 ppm of oxidant (KI Method). We were unable to detect an effect of air pollution on lung function by the method used at that time.

A second method used was to study the same group of men repeatedly on days with varying air pollution. During the late summer and fall of 1958, Dr. Charles Schoettlin studied at weekly intervals two groups of men at the Veteran's Administration Hospital, West Los Angeles, one group had chronic lung disease, the second did not. The men in these two groups were matched for age and smoking history. The data are still being analyzed.

In 1956 a portion of the California Health Survey was devoted to questions about air pollution. A probability sample one adult in each 2000 households in California, was asked a number of questions about health and about the extent that air pollution affected them. The respondents were questioned concerning the presence of selected chronic deseases and conditions and what things they felt made them worse. They were also asked about their satisfaction with their home community and with their job. Those who said they were dissatisfied were asked the reasons for being dissatisfied. All these questions were put to the person interviewed before there was any mention of interest in smog or air pollution by the interviewer.

In Los Angeles County, air pollution was spontaneously reported to make eye complaints worse by three persons out of four who had such complaints; asthma and nose and throat complaints were reported to be made worse by air pollution in half, followed by sinus in two out of five, hay fever in three out of ten, bronchitis, shortness of breath and bad headaches each in about one person in five who had the condition.

In answer to the question in the California Health Survey—"Taking everthing into consideration, how satisfied are you now with living in _____ (community), are you very satisfied, somewhat satisfied or not satisfied at all?" One person out of five in Los Angeles answered that they were only somewhat or not at all satisfied, and when asked, "What don't you like about it?" One person out of four reported air pollution as the reason compared to one person in five reporting personal reasons, and one person out of eight reporting community dissatisfaction because of financial reasons. Of the dissatisfied group almost half reported that they were thinking of moving.



Source: State of California, Department of Public Health, Death Records.

Fig. 5

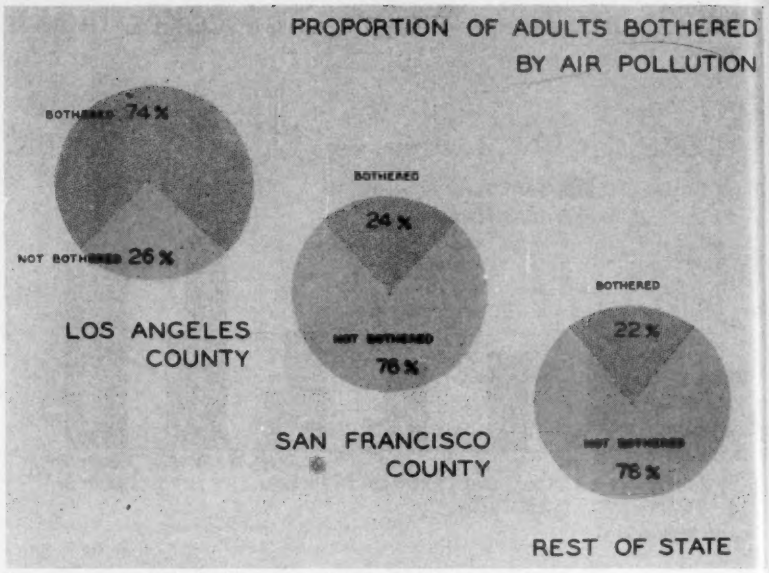
Remember that these questions about health effects and community satisfaction were asked before the interviewer had mentioned air pollution as such. The answers therefore represent spontaneous reactions to air pollution, not stimulated by direct questions about air pollution.

When finally the question—"Lately, there has been a lot of talk about air pollution, such as dust, smog, smoke, etc.; in your community does air pollution (smog) bother you *very much, some,* or not at all?" Two out of three of those interviewed in Los Angeles County reported being bothered (Fig. 6).

When asked, "How does it bother you?" Nine out of 10 persons bothered in Los Angeles reported eye irritation with or without some other symptom. In 1958 these same questions were again asked of a statewide sample, with no important differences from 1956 in the proportion bothered by air pollution in any area. About 10 per cent of those bothered by air pollution reported that it gave them difficulty in breathing. Although this proportion may seem low it represents close to 300,000 adult persons in the state's population.

When asked in the 1956 survey "Have you been thinking recently of changing your job?" "All in all, how satisfied are you with your job, very satisfied, somewhat satisfied or not at all satisfied?" About one person out of 15 in Los Angeles indicated they were thinking about a job shift even though satisfied and one person in five indicated they were not very satisfied, of whom almost half were thinking of changing jobs. But of those two-thirds of respondents in Los Angeles who reported being bothered by air pollution about twice as many were thinking about changing jobs as among the one-third not bothered.

Our philosophy is well expressed by the following quotation: "It should seem possible, by a set of well adapted experiments, accurately made, to discover what are usually called the occult qualities of the air, and render them manifest to the senses. And if by this means, we could come at a tolerable knowledge of the effluvia, salts, and other heterogenous matters, wherewith the air at different times, and in different countries is replete, it might give us almost a complete knowledge of the nature of all epidemic diseases that



Source: State of California, Department of Public Health, California Health Survey.

Fig. 6

may arise for the future, provided due attention be given at the same time to the age, sex, constitution, manner of living, and so forth of the patient; all which circumstances being carefully considered and compared together, might probably direct to rational, fixed, and effectual methods of cure."*

The newest aspect of California's program in air pollution will draw heavily on epidemiology. The California State Department of Public Health has been given one of its most difficult tasks, the establishment of standards for air quality. The statute says in part "The standards shall be so developed as to reflect the relationship between the intensity and composition of air pollution and the health, illness, including irritation of the senses, and death of human beings, as well as damage to vegetation and interference with visibility."

Almost the first problem in this task is to determine which group of persons is to be protected. To protect every *last person* from sensory irritation, his crops from damage, or his wife's wash from any soiling might prove unreasonably expensive.

One basis now being considered for the standards is that they will be designed to protect the most sensitive group of persons in the community, and that these groups are to be defined according to age and medical criteria. This means that standards will be more strict than needed to protect the healthy adult male, (the responsibility of industrial hygiene standards) and perhaps less strict than needed to protect a desperately ill person, (the responsibility of the individual physician). Much of the work in air pollution epidemiology will in the future be based on detecting the most sensitive groups of persons in the population, and on determining their reactivity to various levels of air pollution.

In summary epidemiological studies permit the following conclusions:

1. There has been no convincing evidence that acute sickness or death has resulted from air pollution in California.
2. Lung cancer, chronic bronchitis, and emphysema are chronic diseases whose relationship to air pollution is being studied.
3. Studies concerning the effect of air pollution on important bodily functions are getting underway; they are expected to provide a sensitive method of studying air pollution effects.
4. Population surveys reveal that air pollution causes widespread and disturbing symptoms.
5. Air pollution in Los Angeles has been the commonest cause of community dissatisfaction, and is given as a frequent reason for moving or change of employment.

Air pollution is a threat to health including social health. Epidemiologic studies can provide a well rounded picture of all of these effects, and thus a basis for their prevention through sound community planning and rational controls.

*The entire works of Dr. Thomas Sydenham, newly made english from the originals to which are added explanatory and practical notes from the best medicinal writers; with others by the translator: by John Swan, M.D., London—R. Cave, 1763, pp. 9–10. (The quotation is from a note by the translator).

Graduate EDUCATION *for Air Pollution* CONTROL PERSONNEL*

E. R. HENDRICKSON, Ph.D Research Professor, College of Engineering, University of Florida, Gainsville

Introduction

From the beginning of the Industrial Revolution until fairly recently, the smoky pall which hung over many of the cities of the world was considered a sign of industrial progress. Automobiles, which poured forth thousands of tons of exhaust gases daily, were looked on as evidence of the highest standard of living ever attained. In some predominantly rural areas the agricultural industry and the chemical industry were in conflict over damages to crops allegedly produced by air-borne discharges. When several community air pollution episodes resulted in death and extreme discomfort to large numbers of people, the public began to question this price being paid for "progress." Could not this rapidly advancing technoloy apply some of its talents to preventing air pollution? Progress was found to be possible while still maintaining reasonably clean air and streams. A good start was obtained in cleaning up some of the "smoky" cities prior to World War II. More difficult areas, including some complicated by activities not known prior to World War II, are under continuing investigation.

In order to solve the various facets of the air pollution problems in the world, the work of a number of disciplines has been necessary. Important work on various phases of the problem is being contributed by agriculturists, chemists, engineers, meteorologists, physicists, and physicians among others. Each of these disciplines contributes its share toward determining causes and effects, estimating dispersion patterns, designing control devices, and assessing the extent of pollution. Experts in each of these areas contribute their special skills to the solution of part of the problems. Each must learn a little of the work and sphere of knowledge of the other and, perhaps more important, each must understand and appreciate the problems of the other. An understanding must be developed in these various disciplines of the philosophy and interrelation of waste disposal practices.

There are only three possibilities for the ultimate disposal of the wastes from our communities and industries—land, water, and air. In some instances the elimination of pollution problems in one medium merely transfers them to another. For example, the incineration of rubbish to eliminate extensive dumps may result in pollution of the atmosphere. The alleviation of atmospheric pollution by scrubbing stack gases and discharging the effluent to the nearest watercourse may result in stream pollution. All waste disposal problems are thus interrelated and it is essential that those concerned with air pollution control be familiar with disposal practices in other media.

In speaking of stream pollution you have frequently heard the statement "dilution of pollution may not be the solution." The same might be said to be true in the case of air pollution problems. There are a number of similarities between the two. The atmosphere has an unknown but not unlimited capacity to disperse air-borne materials. As in the case of streams, some areas are not so favorable for the dispersion of gases and aerosols as are others. A single source of pollution in the area may be satisfactory and result in no problem, but more of the same or similar types may overload the atmosphere. It is felt, therefore, that control of air pollution is ultimately an engineering problem. All of the other disciplines previously mentioned are involved to a considerable extent, but once the material gets into the air little can be done about it. Emissions must be controlled at the source to such an extent as to limit undesirable concentration. For this reason and because most of the existing graduate courses in air pollution control are intended for engineers, this discussion will be concerned primarily with graduate training for engineers in this important area of work.

Demands for Special Training

Most of us who are presently engaged in research and investigation in air pollution have had no specialized training. Apparently most of these scientists and engineers, however, have been well educated in the basic sciences and certain applied sciences. As the control of air pollution has become more critical, it has been necessary for persons with a variety of backgrounds to grasp specific applications by experience or by educated trial and error. In the early stages of air pollution control, some of the results were amazingly successful while others were tragic. Public demands for air pollution control programs have grown explosively in the last two years. During the last major legislative year, control legislation was introduced in the legislature of more than 20 states. Numerous cities and counties of all sizes have passed appropriate ordinances setting up control agencies. Unfortunately, the public expects results in a relatively short time. These requirements, along with the numerous research and development activities, have resulted in a tremendous demand for trained personnel. In order to produce the quickest results in the shortest period of time, it appears that special training is desirable.

Anticipating this demand, the Public Health Service has supported the development of graduate programs embodying specific courses in many phases of air pollution at several universities in the country. At the present time such curricula are established at the Universities of California, Cincinnati, Florida, Harvard, Michigan, Minnesota, North Carolina, Pittsburgh, Rutgers, Washington, and Georgia Tech. Most of these programs involve work leading to a graduate degree. Some institutions offer special concentrated courses which may or may not be used in a degree program. These have been offered by Columbia, Massachusetts Institute of Technology, and New York University. Most of the courses have been

* Presented at the 52nd Annual Meeting of APCA, June 21–26, 1959, at the Statler Hotel, Los Angeles, Calif.

developed in conjuction with departments of sanitary engineering. Some of them are under the administrative control of graduate schools and others, of schools of public health.

The information to be reported in this paper resulted from questionnaires sent to the program directors at each institution where the author had knowledge of special courses in air pollution control. Some of this work was undertaken as part of his duties as Chairman of the Task Force on Education, Committee on Atmospheric Pollution of the American Society of Civil Engineers. Specific programs and courses will not be described because this information can be obtained in more recent form from the individual institutions. The author was drawn liberally on the philosophy stated by the respondents to the questionnaires. From these can be drawn conclusions regarding the types of curricula which it is desirable to offer in order to meet the immediate and future needs for air pollution personnel.

Consideration of problems of providing graduate education for air pollution control personnel reveals two areas where difficulty is experienced in developing new courses:

1. The type of training most suitable.
2. The administrative problems of the institution.

Type of Training Desirable

Whether from the point of view of an industry, control agency, or research agency, the engineering training desirable for control personnel embodies the features commonly found in sanitary, chemical, and mechanical engineering curricula. The sanitary engineer has a reasonable background in chemistry, an appreciation of the interrelationships of waste disposal practices, and the knowledge of the effects of environmental factors on human health. The chemical engineer has a better background in chemistry, and a knowledge of unit processes. The mechanical engineer has special knowledge about combustion processes and instrumentation. All of these lines of training, however, fall short in meteorology, physiology, and toxicology. All modern engineering curricula appear to be adequate in the basic sciences with the possible exception of chemistry.

Since existing undergraduate curricula are already overcrowded, the logical conclusion must be drawn that any special training should be in the form of a series of graduate courses whether or not they lead to a degree. As pointed out previously, the basic training of sanitary engineers, chemical engineers, and mechanical engineers seems to be most suitable for advanced study in air pollution control, while at the same time complicating the problem of program design. All of them have somewhat different backgrounds and all of them have some deficiency which must be made up. These three fields of engineering constitute by far the largest number of students presently engaged in advanced training of the type described. Because of their varied preparation, it is essential to bring them all to some common level by means of "background" courses. With the possible exception of some sanitary engineers, all of them need training in toxicology and physiology and all need training in meteorology. Sanitary and mechanical engineers should have chemistry courses carrying them through physical chemistry and should develop an understanding of unit processes. Chemical and mechanical engineers need to develop an appreciation of pollution control problems plus liquid and solid waste treatment practice. Sanitary and chemical engineers should have additional training in combustion processes. At some stage in their training, all of the students would receive special training in problems peculiar to air pollution control.

The development of a program embodying features just described may be different for each different institution. Some of the most difficult development problems are administrative in nature.

Institutional Problems

Since it appears essential that the type of training under consideration be given as part of a graduate program, the curricula traditionally will be administrated by a graduate school or a school of public health. Most graduate schools have traditional and frequently inflexible regulations concerning administration and the organization of a degree program. Schools of public health appear to be somewhat less rigid in this respect. Many graduate schools require that a program be taken in major and minor fields of study. The major field of study is usually in a single administrative unit such as a department or college. This frequently complicates development of a schedule of courses for an individual student by excluding some desirable courses from his major or minor field because they are not given in a certain department and requiring that these courses be taken as foundation without any credit toward a degree.

Another administrative difficulty encountered in most institutions involves the sequence arrangement of courses resulting in the requirement of prerequisites. The requirement that a student have certain prerequisites is essential to the education process, insuring a logical sequence of learning with each new subject based on a firm foundation. This frequently makes it difficult to schedule a series of courses in proper sequence within a given period of time. Since it is not the intention of a program of this type to merely train technicians, it is important that the students know the why as well as the how. The system of prerequisites does, however, introduce one further complication in attempting to provide training in a special area such as air pollution control for persons who have not received their baccalaureate degree in a similar field of endeavor. For example if a program of this type is administrated in a graduate department of sanitary engineering, a student with a Bachelor's degree in chemistry could possibly not enroll. It is usually possible, however, for him to enroll in the chemistry department for graduate training and take the special courses as part of a minor.

Difficulties in scheduling frequently create problems for the student attempting to complete a Master's degree in one year. This is especially true if he enters in the middle of a sequence of courses, such as the beginning of the second term. Most institutions of higher learning are experiencing a shortage of personnel, funds, and space and are thus limited in their ability to schedule special courses every term.

Because of the variety of subject material required in a special training program for air pollution control, it is essential that some of these administrative problems be resolved. In the institutions previously mentioned, in both graduate schools and schools of public health, they have been resolved to a great extent. The institutions have cut across lines of tradition and set up well-rounded programs with a minimum of scheduling difficulty. This is despite the fact that a variety of disciplines may be represented among entering students. Usually a single department serves as the administrative core which awards the degree, but the resources of a number of departments contribute to the success of the over-all program.

Existing Course Work

Questionnaires were sent to all accredited institutions known by the author and the Air Pollution Program of the Public Health Service to be offering courses in various phases of air sanitation. Replies were received from those institutions previously listed. The questionnaires were designed to determine specific courses available at each university, the level of those courses, the departments involved, the degrees granted, and the general philosophy concerning the course offerings. In all cases the courses in air pollution control were part of a degree program, although in some instances the courses were available to qualified

persons not working for a degree. At a relatively few institutions, courses were scheduled for the convenience of non-degree students. Qualification as a graduate student was required in most institutions, but in several the courses were available under special conditions to advanced undergraduates of high standing. In no instance, would a Master's or higher degree be granted, based entirely on work in air pollution courses.

All of the institutions expressed the philosophy that it was undesirable to merely train technicians in these programs. It was felt that the institutions of higher learning should direct their efforts toward the training of professional specialists in the area of environmental hygiene or sanitary engineering. In this context, sanitary engineering is given the broad definition adopted by the National Research Council in 1954. Training is usually offered in the broad aspects of sanitary engineering, supported by advanced work in the basic sciences, and with specialized air pollution courses as applicable. In general this philosophy follows that adopted by the Conference on Education, Training, and Utilization of Sanitary Engineers conducted by the National Research Council in 1957. In nearly all instances reported, the program is administered by a department which might be broadly described as sanitary engineering. Although most of the courses are intended for engineers, non-engineers can qualify at many of the schools.

In reviewing the returned questionnaires, a number of specific subjects in the field of air pollution control became evident. Eight institutions reportedly offered courses in the general principles of atmospheric pollution. Eight offered special courses in the control of air pollutants and eight offered courses dealing with air pollution sampling and analysis. The eight were not the same in all cases. Six of the institutions reported offering courses in meteorology with several of them having two courses in this area and one university offering three courses. Field experience in all phases of air pollution control was specifically designated by a course title in four institutions. Four of the departments reported special courses in toxicology of air pollutants. Nearly all of those reporting had additional courses in the fields of industrial hygiene, environmental sanitation and public health engineering which had a direct bearing on matters appropriate to air hygiene but which were not specifically designated as such.

As far as could be determined, the eight departments reporting a course in the general principles of air pollution offered similar material. In general the courses served as an introductory study of the atmosphere as a place of disposal for certain industrial and community effluents. The usual subject material covered included sources of pollutants, effects of air pollution, classification of wastes, the effects of micro-meteorological factors on dispersion, problems of sampling and analysis, and discussion of abatement programs. This format varied somewhat from one institution to another, but in general followed the same pattern.

Courses in the control of pollutants also tended to follow a typical pattern. They were mainly concerned with the theory and application of methods and devices to control emissions from industrial unit processes and air-borne community effluents.

Air pollution sampling and analysis, which war reportedly offered by eight of the institutions, generally considered the theory and practice of sampling and analysis of air-borne materials. The material usually covered the special techniques and problems encountered in obtaining representative air samples in the free atmosphere and in ducts. Special physical, chemical, and biological techniques of analysis as well as available instrumentation were also considered.

A number of different approaches are being used for special courses in micrometeorology. In general, however, a comprehensive review is made of meteorology and the physics of the lower atmosphere as they effect the dispersion of gases and aerosols. At some institutions, depending on the personnel and facilities available, special courses age given in diffusion theories and empirical approaches plus consideration of applicable meteorological techniques as applied to air pollution problems. In others, these subjects are covered in the basic course.

Time does not permit a discussion of each of the various applicable courses at the institutions described. A great variety of them are available under numerous course titles and departmental designations. Some of the departments have initiated no new courses to cover this new area of endeavor, depending on modification of existing courses to serve the purpose. The majority, however, have developed two to six new, specific courses intended to strengthen an existing program with this new facet of environmental hygiene.

Conclusions

Considerable pressure has been placed on institutions of higher learning in recent years by industry, by control agencies, and by research institutions to develop specialists in many phases of air sanitation in a relatively short period of time. Unfortunately each group feels that different requirements must be satisfied. To meet the various demands, dozens of new courses would have to be initiated at each institution. Graduates of courses of this type would be very highly specialized in a very narrow field of knowledge. The desirability of this condition is doubtful. It is questionable whether a pay load for the courses could be obtained and it is doubtful that the graduates of such programs would be of any real value. It is my personal opinion that the institutions presently providing specialized training in the field of air pollution control are doing a good job and in the proper manner. In the long run, graduates of such programs will be of more value both in air pollution control and in related activities. If experience proves the necessity for additional specialization, the demand will undoubtedly be met.

Many of the departments involved have done an excellent job in cutting through some of the undesirable red tape of tradition and co-ordinating the contributions of various teaching and research units. For some of the universities, this has been accomplished for the first time.

Teachers of some of the new courses in air sanitation find a great deal of similarity with some of the subject matter they teach in the more traditional sanitary engineering courses. For example, the theory of a small particle settling in air and water is the same. Only the fluid viscosities and densities are different. Design of certain types of equipment is based on the same principles whether water or air is the carriage medium. It is possible that these realizations may eventually revolutionize the teaching of sanitary engineering subjects. The demand for specialized courses in air hygiene may thus be responsible for a new approach to teaching the engineering phases of environmental sanitation.

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PARTICULATE *Pollutants* IN THE *Air* OF THE *United States**

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The National Air Sampling Network is comprised of sampling sites in selected cities and nonurban areas throughout the United States and its Territories. The primary objective of the Network is to obtain information on the nature and extent of air pollution over the United States, which may be of value in evaluating the over-all problem and in planning more detailed studies. As such, the Network is not intended to substitute for intensive community air pollution monitoring, rather, the Network should stimulate such local activities. In line with the purpose of the Network and in order to give more complete coverage of the United States, sampling is limited to a single site in a given area. An additional limitation is placed on the collection of samples, in that at each site one 24-hour air sample is collected each two-week period.

In operation since 1953, the National Air Sampling Network has collected a large quantity of data concerning the concentrations of suspended particulate air pollutants in the United States. A summary report of all data collected through 1957 was published in November, 1958.[1] The report is essentially a tabulation of data with only a minimum of explanation or interpretation. This paper reports the results of statistical analyses of the suspended particulate data contained in that report, as well as of additional data collected in 1958 and it treats in succession three major topics:

(1) Establishment of the mathematical form of the distribution of particulate levels.

(2) Discussion of parameters which may be used to define these distributions.

(3) Use of these descriptive parameters in drawing conclusions as to the suspended particulate pollution in the air of the United States.

Mathematical Form of the Distributions

Generally, a statistical analysis of sampling data presupposes knowledge of the theoretical distribution function of the universe from which the sample was selected. One of the most frequent assumptions made by the investigator is that the observations are drawn from a population which can be described by a normal or Gaussian function, i.e., the familiar symmetrical bell-shaped curve. Two reasons for this assumption are that (1) many distributions have been found to be approximately normal and (2) the mathematics of sampling from a normal population have been highly developed. Also, special probability graph paper is available on which the cumulative frequency function of a normal population plots as a straight line. This characteristic of a normal population provides a rapid method for testing a distribution to determine its approximation to normal.

When the cumulative frequency distributions of suspended particulate levels for all urban and nonurban sites for 1957–58 are plotted on normal probability paper (Table I, Fig. 1), the result is obviously not a straight line. For both distributions there is definite upward curvature to the points plotted, implying a skewness (i.e., a long tail) to the right. This skewness suggests a possible transformation resulting in a newly formed variable which would itself be approximately normally distributed. When the cumulative frequency distributions are plotted on logarithmic probability paper (Fig. 2), the results do appear to be linear. It has been found that, in general, the concentrations of particulate matter appear to be log-normally distributed, i.e., the logarithms of actual concentrations are nearly normally distributed.

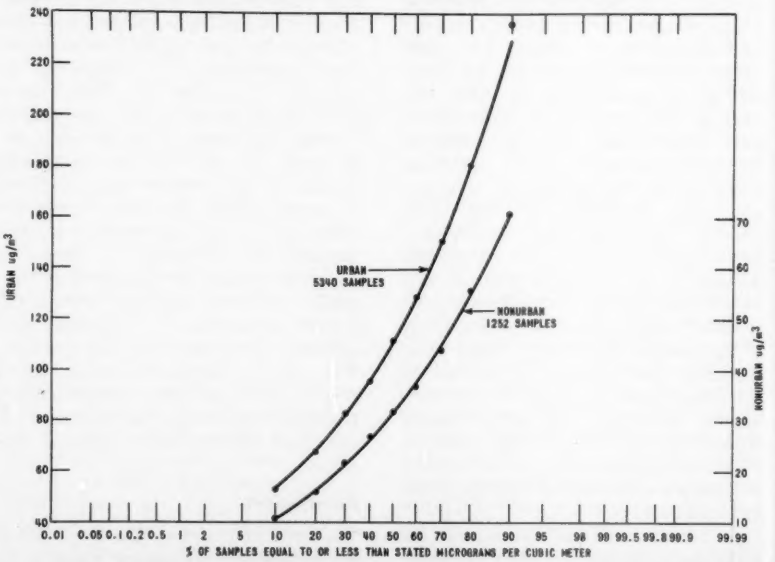
URBAN µg/m³
NONURBAN µg/m³
URBAN
5340 SAMPLES
NONURBAN
1252 SAMPLES
% OF SAMPLES EQUAL TO OR LESS THAN STATED MICROGRAMS PER CUBIC METER
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99

Fig. 1. Cumulative frequency distributions. Suspended particulate matter. All urban and nonurban stations. Arithmetic probability plot. 1957–1958.

* Presented at the 52nd Annual Meeting of the Air Pollution Control Association, Statler-Hilton Hotel, Los Angeles, Calif., June 21–26, 1959.

Table I—National Totals 1957–58, Suspended Particulate Levels ($\mu g/m^3$)

Stations	No. of Samples	Min.	Frequency Distribution—Percent 10	20	30	40	50	60	70	80	90	Max.
Urban	5340	11	53	68	83	96	112	129	151	181	236	978
Nonurban	1252	1	11	16	22	27	32	37	44	56	71	460

Table II—Annual Site Distributions of Suspended Particulate Levels Showing Departure from Log-Normal (1957 Data)

City	No. of Samples	Min.	Frequency Distribution—Percent 10	20	30	40	50	60	70	80	90	Max.
Minneapolis[a]	26	42	52	72	88	94	109	126	135	164	193	722
Tampa[b]	26	34	55	61	67	70	76	81	85	94	100	168
East Orange[c]	20	26	29	34	52	72	118	145	158	179	228	366
Honolulu[d]	26	30	33	34	37	39	41	43	48	58	76	87

[a] Slight skewness.
[b] Peaked kurtosis.
[c] Flat kurtosis.
[d] Extreme skewness.

It is not reasonable to suppose that all distributions of concentrations of particulate matter will be exactly log-normal. However, slight departures from normal are acceptable and present no real difficulty in a statistical analysis. Whether a given frequency distribution is log-normal is commonly decided by visual estimation, i.e., points of the cumulative frequency distribution plotted on log-probability paper appear to be on a straight line. It is possible to reinforce or supplant this qualitative estimation by tests of normality which yield numerical measures. In the study of a large number of distributions the mathematical tests are more practical, as the routine computations may be delegated to an electronic computer.

For the mathematical tests for log-normality in this study, annual site data for the years 1953–57 were used. Prior to 1957, sampling was done on a weekly basis at most stations and daily at a few stations. Since January 1, 1957, sampling has been carried out on a random schedule[2] which provides for the collection of one 24-hour sample in each two-week period (26 per year). Due to the sample size, ordinary methods for testing the departure from normal[3] are inadequate. Geary and Pearson,[4] however, provide a modified method for samples fewer than 100. Even this test fails to detect anything but gross differences when the sample size is less than 20. The discussion of departure from normal is, therefore, restricted to a sample size of 20 or more.

There were 233 such annual site distributions for which the number of samples was 20 or more. Of this total, 54 deviate significantly from log-normal, according to criteria defined in the Geary and Pearson paper. Closer investigation reveals that 29 of the 54 show skewness to the right or left, which is the result of either one extremely high or low value. This type of non-normality is not evident from the graph of the deciles on log-probability paper, as illustrated by the Minneapolis data (Table II, Fig. 3) in which case the maximum is 722 compared to a 90% value of 193 $\mu g/m^3$. For distributions of this type the exclusion of the extreme value results in the acceptance of the hypothesis of log-normality. This form of departure from normal does not invalidate the use of ordinary statistical tests. In fact, if the standard geometric deviation is estimated from the probability plot, the effect of the one extreme value is minimized.

For nine distributions, the departure from normal is in the form of peaked kurtosis, i.e., there are a large number of values near the center and a small number near the extremes of the distributions. Again, this type of nonnormality is not evident from the plots of the deciles on log-probability paper as illustrated by the Tampa data (Fig. 3). These distributions are characterized by a minimum appreciably less than the 10th percentile and a maximum appreciably greater than the 90th percentile. Again, no serious discrepancy will result if these are considered as log-normal. Estimating the standard geometric deviation from the probability plot will again tend to minimize the effect of this type of nonnormality.

The balance of the 54 distributions in question, only 16 (Table III) out of the 233 involved, exhibit evidence of nonnormality of types that can result in incorrect conclusions in making significance tests or predictions. Fortunately, these distributions are small in number (less than seven percent of the total) and are usually easily detected when the cumulative frequency distributions are plotted on log-probability paper (Fig. 4). The distribution for Honolulu shows a type of pronounced skewness caused by a number of values differing greatly from the geometric mean. Nonnormal distributions of this

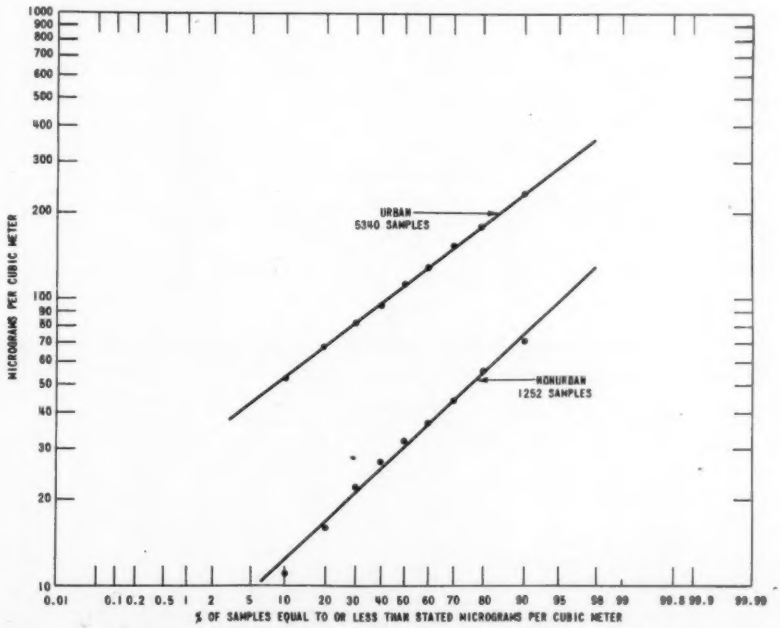

Fig. 2. Cumulative frequency distributions. Suspended particulate levels. All urban and nonurban stations. Logarithmic probability plot. 1957–1958.

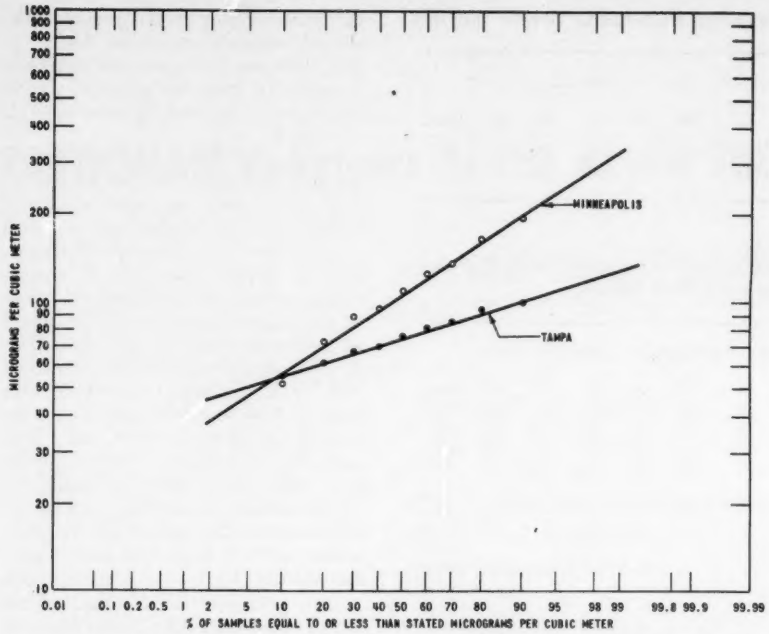

Fig. 3. Cumulative frequency distributions. Suspended particulate levels. Slight departure from log-normal. 1957 data.

type are characterized by an upward curvature of the plot on log-probability paper. Another group of distributions exhibits kurtosis in the form of flatness, i.e., the values are spread over a considerable range. Distributions with this type of nonnormality show up as an "S" curve on log-probability paper, as for example, the data for East Orange (Fig. 4). These two forms of departure from normal may affect the reliability of statistical tests based on normal theory.

In the light of the test for normality it seems plausible to conclude that, in general, concentrations of particulate matter are log-normally distributed. When statistical analyses are performed on specific distributions, the degree of departure from normal should be estimated by plotting the cumulative frequency distributions on log-probability

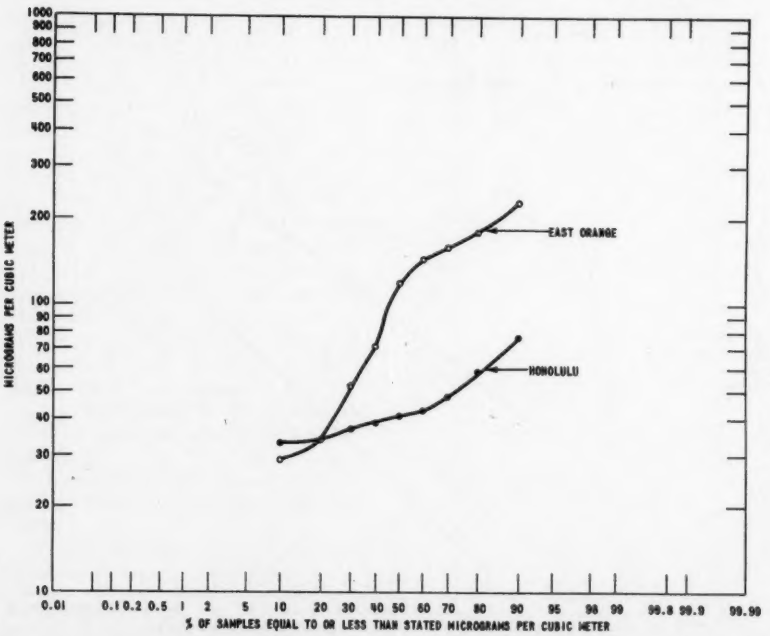

Fig. 4. Cumulative frequency distributions. Suspended particulate levels. Significant departure from log-normal.

Table III—Annual Site Distributions Showing Extreme Deviation from Log-Normal

Station	Site	Year
Anchorage, Alaska	1	1955 & 1957
Berkeley, Calif.	1	1954
Charleston, W. Va.	1	1954
Charleston, W. Va.	2	1955 & 1956
Chattanooga, Tenn.	2	1954
East Orange, N. J.	1	1957
Honolulu, Hawaii	1	1956 & 1957
Philadelphia, Pa.	1	1955
San Leandro, Calif.	1	1956
Scranton, Pa.	1	1957
Tampa, Fla.	1	1954
Waimanalo, Hawaii[a]	1	1957
Youngstown, Ohio	1	1956

[a] Nonurban station.

paper. This estimate will serve to indicate the reliability of the analysis.

Descriptive Parameters

The equation of the log-normal distribution is:

$$y = \frac{N}{\log \sigma_g \sqrt{2\pi}} e^{-\frac{(\log x - \log \bar{x}_g)^2}{2 \log^2 \sigma_g}}$$

where

π = a constant, approximately 3.1416
e = a constant, approximately 2.7183
σ_g = a parameter, called the standard geometric deviation
$\bar{x}_g$ = a parameter, called the geometric mean
x = the abscissa, or a measurement on the x axis of some variable like the concentration of suspended particulate
y = the ordinate, corresponding to the frequency of an assigned value of x
N = the total number of observations of the variable.

From this equation, it is apparent that a log-normal distribution may be described by two parameters—the Geometric Mean ($\bar{x}_g$) and the Standard Geometric Deviation (σ_g). These two parameters may be computed directly from the raw data using methods described in any statistical text.[5] It is also possible to estimate these parameters from a plot of the cumulative frequency distribution in the form of deciles as listed in Reference 1.

To better understand the procedure involved in making these estimates, it is perhaps wise to refer briefly to normal distribution theory. Since the normal curve is symmetrical, the mean and the median (i.e., the 50th percentile) coincide (Fig. 5). Also, if the area under the normal curve is assumed to be unity, it can be shown that 0.6826 of this area is contained in the interval $\bar{x}_g \pm \sigma_g$, or that 0.8413 of the area lies to the left of

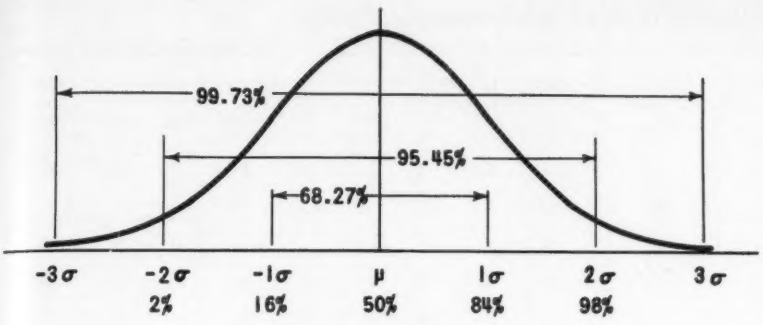

Fig. 5. Normal distribution curve.

Table IV—Deciles and Normal Deviates

Deciles	10	20	30	40	50	60	70	80	90
Normal deviate	−1.282	−0.842	−0.524	−0.253	0	0.253	0.524	0.842	1.282

Table V—Comparison of Geometric Means and Standard Geometric Deviations Computed from Original Data and from Nine Deciles

No. of Samples	Geometric Mean: Original Data	Geometric Mean: Nine Deciles	Geometric Mean: Percent Difference	Standard Geo-deviation: Original Data	Standard Geo-deviation: Nine Deciles	Standard Geo-deviation: Percent Difference
26	110	109	−0.9	1.66	1.60	−3.6
26	130	130	0	1.40	1.46	4.3
26	50	50	0	1.41	1.45	2.8
26	195	199	2.0	1.51	1.46	−3.3
24	109	107	−2.0	1.58	1.68	6.3
25	108	109	0.9	1.27	1.30	2.4
26	100	101	1.0	1.38	1.33	−3.6
26	127	127	0	1.44	1.48	2.8
26	89	90	1.1	1.57	1.49	−5.0
26	128	129	0.8	1.35	1.37	1.5
26	174	175	0.6	1.42	1.44	1.4
26	160	154	−3.8	1.52	1.46	−4.0
25	107	112	4.7	1.79	1.76	−1.7
25	174	175	0.6	1.38	1.42	2.9
26	119	117	−1.7	1.29	1.30	0.8
26	83	81	−2.4	1.39	1.41	1.4
22	192	192	0	1.36	1.38	1.5
26	44	43	−2.3	1.35	1.36	0.7
26	107	109	1.9	1.46	1.47	0.7
26	52	50	−3.8	1.50	1.43	−4.6
26	91	91	0	1.56	1.54	−1.3
26	156	159	1.9	1.34	1.34	0
25	186	192	3.2	1.43	1.47	2.8
26	104	101	2.9	1.69	1.72	1.8
23	176	174	−1.1	1.70	1.78	4.7

$\bar{x}_g + \sigma_g$. Therefore, theoretically, it is possible to compute the standard deviation as the difference between the 50.00% and 84.13% points of the cumulative frequency distribution. For log-normal distributions the geometric mean is equal to the 50th percentile. The standard deviation of the logarithms is the difference between the log of the values at the 84th and 50th percentile points. Upon taking antilogs, the standard geometric deviation is merely the ratio of the concentration at the 84th percentile to the concentration at the 50th percentile. Figure 2 can be used to illustrate the method of graphically estimating the two parameters. The estimate of the geometric mean is 112 and the 84th percentile is 200. Thus, the estimated standard geometric deviation is 1.78. This example is based on a distribution which is very nearly log-normal.

As stated previously, in actual practice a distribution may deviate slightly from log-normal and consequently points of the cumulative frequency distribution (deciles for Network data) may not all fall on a straight line. Instead, a line is fitted to the points and the 50th and 84th percentiles are estimated from the fitted line. Graphically fitting a straight line to a probability plot provides a satisfactory estimate of the parameters for an individual distribution. In the study of data from a large number of sampling sites, the mathematical method needed is such that the repetitive computations can be done by an electronic computer.

To fit a straight line to the decile values, using the least squares method, it is necessary first to express the deciles in terms of standard deviation units, referred to as normal deviates (Table IV). Following this procedure each point can be expressed in terms of an x and a y co-ordinate. The x co-ordinate is the normal deviate corresponding to a particular decile, and the y co-ordinate is the logarithm of the concentration for that decile. The geometric mean is the value of the y intercept of the fitted line corresponding to a normal deviate

Table VI—Suspended Particulate Matter—Urban Stations—Region and Grand Totals

Station	Years	No. of Samp.	Micrograms per Cubic Meter: Min.	Frequency Distribution, percent: 10	20	30	40	50	60	70	80	90	Max.	Arith. Avg.	Geo. Mean	Std. Geo. Dev.
New England Total	57	58	595	20	42	53	64	75	86	100	118	138	178	326	100	86	1.739
Mid Atlantic Total	57	58	714	23	60	76	93	106	126	144	171	199	262	607	146	125	1.772
Mid East Total	57	58	516	27	54	66	78	88	101	118	135	160	216	745	123	103	1.698
South East Total	57	58	578	15	55	66	80	90	99	118	137	158	223	640	125	104	1.689
Mid West Total	57	58	967	11	74	92	109	121	137	156	179	206	267	978	158	139	1.629
Great Plains Total	57	58	503	22	63	79	93	105	123	134	156	178	223	722	136	120	1.622
Gulf South Total	57	58	516	14	53	64	75	88	98	115	132	151	207	630	118	100	1.687
Rocky Mountain Total	57	58	247	15	37	53	62	72	87	96	117	135	174	466	99	84	1.809
Pacific Coast Total	57	58	704	11	42	58	76	89	115	128	161	192	263	639	136	109	2.026
Grand Total	57	58	5340	11	53	68	83	96	112	129	151	181	236	978	131	111	1.772

Table VI—Suspended Particulate Matter—Nonurban Stations

Station	Years	No. of Samp.	Micrograms per Cubic Meter — Frequency Distribution, percent — Min.	10	20	30	40	50	60	70	80	90	Max.	Arith. Avg.	Geo. Mean	Std. Geo. Dev.
Acadia National Park, Me.	58	22	13	14	15	18	21	24	29	34	42	48	54	27	24	1.688
Clarion County, Pa.	58	21	15	15	22	26	29	32	35	37	48	61	64	34	31	1.635
Pulaski County, Ky.	58	23	12	20	31	33	36	40	43	48	54	58	61	40	38	1.461
Cape Hatteras, N. C.	58	23	19	21	26	27	29	30	33	37	42	52	86	35	31	1.381
Shenandoah Park, Va.	58	25	12	13	15	21	23	26	29	34	37	61	65	30	26	1.748
Holly River Park, W. Va.	58	23	16	19	27	28	29	30	31	33	35	52	68	32	30	1.342
Gulf Shores Park, Ala.	58	22	12	15	17	20	22	27	30	32	36	47	49	27	25	1.557
Florida Keys, Fla.	58	25	7	10	16	18	22	25	29	34	37	61	198	34	24	1.872
Oatland Island, Ga.	58	26	19	24	26	31	34	41	47	49	64	69	97	44	40	1.561
Jackson County, Miss.	58	23	13	17	21	23	26	29	31	33	35	41	47	28	27	1.388
Sangamon County, Ill.	58	24	23	29	37	47	54	59	64	72	79	93	109	60	56	1.551
Montgomery County, Ind.	58	26	26	29	37	44	49	57	64	69	79	85	98	57	54	1.529
Huron County, Mich.	57	22	10	11	16	20	33	36	39	42	61	79	111	40	33	2.038
	58	22	7	11	17	22	27	29	31	52	72	85	156	44	31	2.205
	57–58	44	7	11	18	25	29	32	37	48	67	82	156	42	32	2.112
Door County, Wis.	58	20	7	11	20	23	26	37	42	47	52	72	172	42	32	1.971
Cook County, Minn.	58	23	8	11	15	18	29	35	41	48	57	72	173	44	30	2.131
Shannon County, Mo.	58	23	18	19	26	28	30	38	40	41	43	57	71	37	34	1.469
Thomas County, Nebr.	58	26	9	13	14	16	18	21	29	37	52	65	101	31	25	1.979
Ward County, N. D.	58	26	3	8	10	13	16	26	30	33	41	61	83	28	21	2.254
Black Hills Forest, S. D.	58	22	5	6	7	11	15	16	22	25	41	72	99	26	17	2.591
Montezuma County, Colo.	58	26	4	5	6	8	10	14	15	16	18	28	33	14	11	1.932
Craters Moon, Idaho	58	22	5	5	7	8	16	22	26	33	37	44	56	23	17	2.523
Glacier National Park, Mont.	58	26	1	4	6	7	7	8	11	12	24	26	225	20	9	2.066
Bryce Canyon Park, Utah	58	23	4	5	8	10	16	22	37	85	139	269	403	83	29	5.051
Port Woronzof, Alaska	58	25	4	6	10	14	16	19	21	26	29	37	83	22	17	1.940
Waimanolo, Hawaii	57	23	23	24	27	30	32	34	36	41	48	76	85	41	36	1.483
Curry County, Ore.	58	20	14	15	17	19	22	29	37	42	65	72	115	40	30	1.964
Grand Total	57–58	1252	1	11	16	22	27	32	37	44	56	71	460	39	30	2.037

of zero (the median) and the standard geometric deviation is the antilog of the slope of the line.

Means and standard geometric deviations were computed for a large number of distributions from the original data by conventional procedures and then from the nine deciles by the procedures just described. The geometric means computed by the two methods differed by an average of less than 0.5%. The estimates of the standard geometric deviation differ by about 1%. Comparisons of the parameters obtained by the two methods for selected distributions are shown in Table V. It appears that the parameters can be estimated from the decile values with a good degree of reliability.

Use of the Descriptive Parameters

Before attempting a study of the levels of particulate pollutants at the various sampling stations it was necessary first to take steps to insure the comparability of data. The criteria used in the selection of data for the following discussions were (1) 1957 and 1958 data alone were considered, (2) at least 20, but not more than 26 samples had to have been collected in any one year, no more than three in any one month, nor more than seven in any quarter, and (3) a year had to consist of all four quarters and a quarter of at least two months. For stations meeting the above criteria, the two parameters and the frequency distributions from which they were derived are shown in Table VI. These criteria insured that a station was not made to appear favorable or unfavorable merely as a result of sampling procedure. Strict adherence to these criteria resulted in the exclusion of data from some stations, especially nonurban stations. While the excluded data are of value as a measure of atmospheric pollution at the sampling sites, they were not acceptable for the statistical analyses in this section of the paper, but were included in the region and grand totals in Table VI.

The two descriptive parameters are of use in both the study of pollution at a specific sampling site and in comparison of data from different sites. For example, they are necessary in testing the significance of observed differ-

Table VI—Suspended Particulate Matter—Urban Stations

Station	Years	No. of Samp.	Micrograms per Cubic Meter — Frequency Distribution, percent — Min.	10	20	30	40	50	60	70	80	90	Max.	Arith. Avg.	Geo. Mean	Std. Geo. Dev.
Waterbury, Conn.	58	23	34	52	59	67	79	91	97	106	118	193	266	100	88	1.596
Hartford, Conn.	57	26	35	52	76	90	100	118	129	136	156	193	314	124	109	1.599
	58	25	28	47	52	65	68	76	85	112	129	156	207	90	81	1.622
	57–58	51	28	46	63	70	81	100	115	129	143	164	314	107	93	1.648
New Haven, Conn.	57	23	51	52	57	61	88	97	105	114	139	158	201	100	90	1.594
	58	25	41	54	59	65	68	75	82	100	112	139	175	84	80	1.448
	57–58	48	41	53	58	63	70	85	96	108	118	149	201	92	84	1.519
Stamford, Conn.	57	26	20	44	67	77	82	100	125	132	171	186	247	112	99	1.740
Bridgeport, Conn.	58	21	46	52	72	81	88	97	118	129	139	179	267	111	99	1.567
Portland, Me.	58	23	44	61	72	81	93	112	129	147	164	228	233	125	111	1.663
Boston, Mass.	57	26	72	81	90	109	121	130	139	156	193	207	214	137	130	1.460
	58	24	72	85	100	118	131	139	164	211	235	255	256	159	149	1.577
	57–58	50	72	82	95	114	125	134	149	179	208	235	256	147	139	1.520
Lawrence, Mass.	57	26	21	37	42	52	57	65	85	90	98	125	186	74	67	1.628
Lynn, Mass.	57	21	43	44	61	74	79	85	112	129	152	193	253	108	93	1.745
Somerville, Mass.	57	26	37	42	52	61	67	79	95	104	114	139	191	87	78	1.598
Worcester, Mass.	57	26	34	41	64	72	93	107	118	132	149	159	219	107	96	1.677
Brockton, Mass.	58	24	23	39	48	55	67	76	85	109	129	164	301	92	77	1.761
Fall River, Mass.	58	23	21	48	57	61	67	79	93	118	164	269	326	114	90	1.907
Quincy, Mass.	58	25	31	44	48	54	59	79	85	96	118	139	224	82	74	1.617
Springfield, Mass.	58	26	20	34	44	49	52	59	72	77	85	95	212	70	59	1.493
Manchester, N. H.	58	20	25	31	44	49	61	67	72	79	85	100	134	68	61	1.536
Providence, R. I.	57	23	73	77	85	89	94	100	118	129	139	179	253	117	108	1.377
	58	26	53	85	90	98	105	118	134	152	193	228	294	135	126	1.495
	57–58	49	53	79	87	93	99	112	123	136	164	211	294	127	116	1.454
Burlington, Vt.	57	26	24	33	36	40	43	49	57	61	76	79	83	52	50	1.453
	58	26	22	26	29	38	41	44	50	54	61	81	156	50	44	1.528
	57–58	52	22	27	33	39	42	46	52	58	75	81	156	51	47	1.540
Wilmington, Del.	57	26	77	95	109	129	139	164	181	193	269	317	481	189	165	1.604
	58	23	53	61	112	123	134	164	193	238	259	346	412	185	161	1.852
	57–58	49	53	90	111	126	139	164	181	228	262	331	481	187	163	1.660
Atlantic City, N. J.	58	25	33	46	50	57	61	66	69	76	85	118	136	70	67	1.399
Elizabeth, N. J.	58	23	56	61	93	100	109	125	139	152	164	228	278	135	122	1.565
Camden, N. J.	57	26	54	125	139	158	174	205	236	253	281	305	352	210	199	1.458
Jersey City, N. J.	57	26	99	112	122	135	144	159	176	187	211	228	311	166	159	1.338
East Orange, N. J.	57	20	26	29	34	52	72	118	145	158	179	228	366	121	90	2.409
Newark, N. J.	58	22	33	44	55	64	69	85	95	123	139	164	231	97	85	1.697
New York, N. Y.	57	25	94	118	144	159	170	187	202	228	269	336	330	197	192	1.468
	58	26	63	69	103	110	115	139	164	183	242	269	389	164	142	1.675
	57–58	51	63	93	109	125	148	168	186	214	253	317	389	180	166	1.615
Binghamton, N. Y.	57	26	54	59	64	72	81	89	96	100	125	139	224	94	88	1.410
Schenectady, N. Y.	57	22	38	44	49	58	65	72	81	89	100	118	143	77	71	1.481
Syracuse, N. Y.	57	26	40	44	67	85	93	105	118	129	152	211	347	119	101	1.724
Utica, N. Y.	57	24	44	57	65	70	100	118	129	152	171	193	228	120	107	1.684
Rochester, N. Y.	58	25	51	79	88	95	100	108	113	129	145	164	232	116	110	1.327
Philadelphia, Pa.	57	25	86	139	149	164	179	211	233	249	259	293	323	203	202	1.366
	58	24	61	85	112	129	152	164	172	185	193	317	349	171	157	1.541
	57–58	49	61	106	134	150	164	177	188	219	249	285	349	187	178	1.448
Pittsburgh, Pa.	57	23	78	81	112	129	164	179	188	211	249	441	534	203	174	1.775
	58	26	85	100	112	126	135	147	160	179	228	269	344	167	154	1.467
	57–58	49	78	93	112	127	143	160	175	193	238	336	534	184	163	1.595
Scranton, Pa.	57	26	62	79	89	100	112	129	179	211	288	307	466	176	147	1.809
Harrisburg, Pa.	58	25	46	57	72	85	95	118	152	193	216	255	292	135	122	1.861
Reading, Pa.	58	25	56	72	87	94	98	112	139	164	183	269	404	142	124	1.638
Wilkes-Barre, Pa.	58	26	23	52	61	72	85	96	107	114	132	164	203	99	92	1.557
Washington, D. C.	57	26	41	52	61	75	82	90	98	105	118	129	258	94	86	1.426
	58	24	66	72	82	88	95	100	112	129	139	164	177	110	105	1.375
	57–58	50	41	61	74	82	89	95	103	115	129	147	258	102	96	1.392
Baltimore, Md.	57	26	77	100	105	113	118	134	152	164	193	242	301	150	140	1.417
	58	25	65	76	85	93	98	109	118	147	164	193	287	127	115	1.451
	57–58	51	65	82	93	102	110	122	139	157	179	238	301	138	128	1.496

ences. From Table VI it can be seen that of the 55 urban sites at which samples were collected in both 1957 and 1958, all but one have different geometric mean levels for the two years. A statistical analysis using the "Student t" test shows that these differences were significant at the five percent level for 11 stations where the mean levels for the two years for the same stations differed by 25% or more. The 1958 levels were significantly higher at Birmingham, Nashville, Tampa, and Wichita and lower at Albuquerque, Denver, New York, Philadelphia, Phoenix, Salt Lake City, and Sioux Falls. At the other 44 stations, the differences between 1957 and 1958 levels were not great enough to be significant.

The relationships between pollution levels in 1957 and 1958 can be illustrated by a study of these 55 stations. They are classified by the descriptive parameters in a two-way table (Table VII). The similarity of the patterns for the two years is apparent. Thus, since the distribution by geometric mean concentration is about the same for both years, the source strength must have remained fairly constant. Likewise, in view of the similarity of the dispersion pattern, analogous weather conditions must have prevailed in the two-year period.

The two parameters for nonurban stations (Table VI) range from nine to 56 $\mu g/m^3$ for the geometric mean and 1.38 to 5.05 for the standard geometric deviation. A classification of the nonurban stations by the two parameters is shown in Table VIII. It is further shown (Fig. 6) that there are apparent geographic differences in these parameters for nonurban stations. The

Table VII—Classification of Urban Stations with Two-Year Data by Geometric Mean and Standard Geometric Deviation

Standard Geometric Deviation	Geometric Mean ($\mu g/m^3$) <75	75–124	125–174	175 & over	Total
1957 only					
<1.3	0	3	1	0	4
1.3–1.49	3	10	8	6	27
1.5–1.69	2	9	5	2	18
1.7–1.89	1	2	1	0	4
1.9 & over	1	0	2	0	3
Total	7	24	17	8	56
1958 only					
<1.3	0	0	0	0	0
1.3–1.49	2	10	9	3	24
1.5–1.69	2	9	8	1	20
1.7–1.89	2	3	2	0	7
1.9 & over	1	2	2	0	5
Total	7	24	21	4	56
1957–58					
<1.3	0	0	0	0	0
1.3–1.49	1	8	11	3	23
1.5–1.69	4	15	7	1	27
1.7–1.89	0	2	1	0	3
1.9 & over	1	1	1	0	3
Total	6	26	20	4	56

Table VIII—Classification of All Non-Urban Stations by Geometric Means and Standard Geometric Deviations 1957–58

Standard Geometric Deviation	Geometric mean ($\mu g/m^3$) <20	20–40	>40	Total
<1.3	0	0	0	0
1.3–1.49	0	6	0	6
1.5–1.69	0	4	2	6
1.7–1.89	0	2	0	2
1.9 & over	5	7	0	12
Total	5	19	2	26

Table IX—Classification of All Urban Stations by Geometric Mean and Standard Geometric Deviation

Standard Geometric Deviation	Geometric Mean ($\mu g/m^3$) <75	75–124	125–174	175 & over	Total
1957 only					
<1.3	0	3	1	0	4
1.3–1.49	7	18	12	8	45
1.5–1.69	3	17	10	5	35
1.7–1.89	1	6	3	1	11
1.9 & over	1	1	2	0	4
Total	12	45	28	14	99
1958 only					
<1.3	1	2	0	0	3
1.3–1.49	4	16	9	4	33
1.5–1.69	6	23	10	2	41
1.7–1.89	3	8	2	2	15
1.9 & over	1	6	3	0	10
Total	15	55	24	8	102
1957–58					
<1.3	1	2	0	0	3
1.3–1.49	7	21	16	6	50
1.5–1.69	9	37	13	3	62
1.7–1.89	1	11	3	3	18
1.9 & over	1	6	2	0	9
Total	19	77	34	12	142

average concentration tends to be higher in the eastern part of the country than in the west. The opposite is true for the degree of variability as measured by the standard geometric deviation. Greater variability is observed for sites in western areas.

The two parameters for urban sampling stations range from 43 to 261 $\mu g/m^3$ for the geometric mean and 1.23 to 2.78 for the standard geometric deviation. The urban stations are also classified by the parameters in a two-way table (Table IX), which shows that approximately 70% of the cities had mean levels less than 175 $\mu g/m^3$ and standard geometric deviations of less than 1.70. The remaining 30% either had geometric mean concentrations of 175 $\mu g/m^3$ or greater, or standard geometric deviations of 1.70 or greater. A mapping of the urban stations similar to that for nonurban stations (Fig. 6) failed to reveal any apparent geographic differences in the two parameters.

It is necessary to consider both parameters in discussing the air pollution potential for a given sampling site. This is illustrated by Fig. 7 in which the four extreme combinations of the two parameters are shown. First is a case in which the mean level is high with a fairly high degree of variability in association, as for example, Gary. For stations in this category, extremely high concentrations are probable. The second case is one in which a rather high mean level is coupled with a small standard geometric deviation, as illustrated by Wheeling. Stations in this category seldom experience very high or very low pollution levels. The next case is one in which the low mean level is accompanied with a high degree of variability between individual measurements, for example, Sacramento. For stations in this category the necessity of considering both parameters is obvious. Noted also is the fact that in spite of the low mean level, and due to the high standard geometric deviation, the level of concentration is occasionally quite high. The final situation is one in which both parameters are low, as for Oklahoma City, in which case high concentrations are unlikely.

From the regional totals (Table VI), in which are grouped the data from individual stations, it can be seen that the standard geometric deviation tends to become larger. This increase conforms to expectations on theoretical grounds, since mean concentrations vary considerably for the various stations and grouping tends to give a very wide distribution of values. In view of this tendency, it is meaningless to compare the standard geometric deviation for a station with that for the state or region in which the station is situated or with that for the nation as a whole. For the

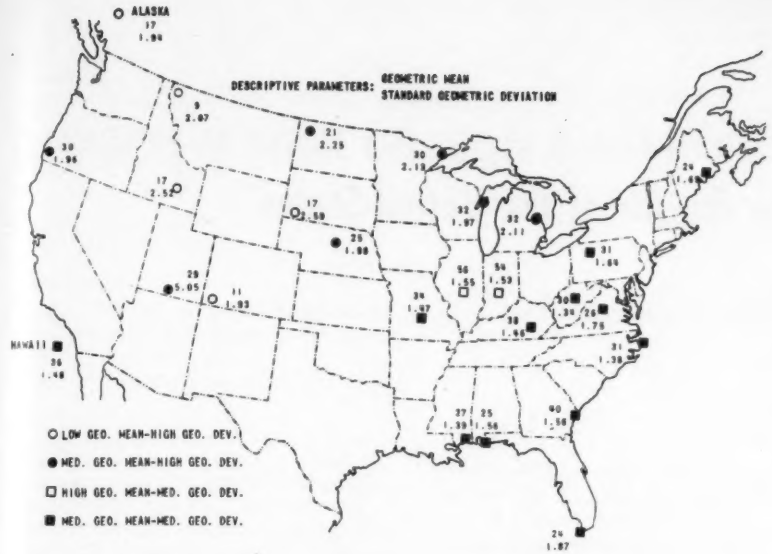

Fig. 6. Descriptive parameters for nonurban stations. 1957–1958.

same reason more reliable comparisons can be made between single years at a given station or between stations for a specific year than between one year and multiple years at a given station.

Summary

(1) It has been shown that a plot of the cumulative frequency distribution on log-probability paper is sufficiently reliable to establish the log-normality of a specific distribution of suspended particulate concentrations. Further, it has been verified statistically that, in general, it is valid to assume log-normality of these distributions.

(2) A method is demonstrated for estimating the geometric mean and standard geometric deviation from a plot of the decile values on log-probability paper. It is also shown that the two parameters can be determined by mathematically fitting a line by least squares to the decile values. A comparison is then made between the parameters as computed by the short-cut method and from the original data.

(3) Use of the geometric mean and standard geometric deviation is described and the necessity for considering both parameters in discussing levels of concentration is illustrated. Geographic differences in the two parameters are apparent for nonurban stations but not for urban stations.

(4) A classification of the urban stations by the two descriptive parameters shows that 70% of the cities had geometric mean particulate concentrations less than 175 $\mu g/m^3$ and standard geometric deviations less than 1.70. The remaining 30% either had geometric mean concentrations of 175 $\mu g/m^3$ or greater, or standard geometric deviations of 1.70 or greater.

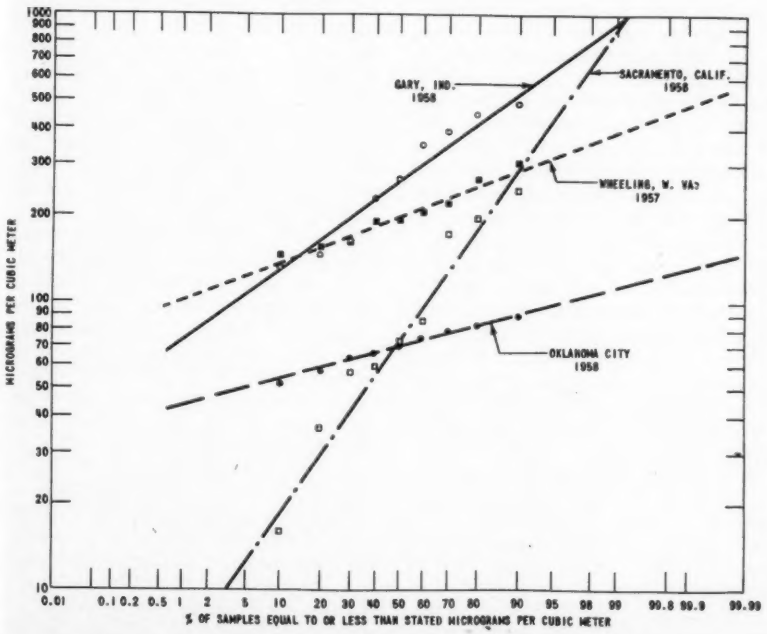
GARY, IND. 1958
SACRAMENTO, CALIF. 1958
WHEELING, W. VA. 1957
OKLAHOMA CITY 1958
MICROGRAMS PER CUBIC METER
% OF SAMPLES EQUAL TO OR LESS THAN STATED MICROGRAMS PER CUBIC METER

Fig. 7. Cumulative frequency distributions. Suspended particulate levels. Urban stations. Variations in descriptive parameters.

Acknowledgment

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(*See comments on next page*)

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APCA Publications Expand Frequency in '60

As of January 1, 1960, THE JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION will expand into a bi-monthly publication with issues appearing in February, April, June, August, October, and December.

The expansion will mean that the JOURNAL will not only appear more often, but will contain more technical papers, news items, and abstracts. It will combine the other two publications into one.

The Abstracts, however, will still be published alone in the alternate months as we are under contract with Public Health Service.

The changeover will not only be advantageous from the readers' viewpoint with more timely, interesting and challenging material, but it will be a great savings time and money-wise for the Association. Eventually the JOURNAL may become a monthly publication, but this is a slow process.

COMMENTS on "Particulate Pollutants in the Air of the United States"

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Editor's Note: The comments contained in this paper were presented orally by Dr. Walter A. Quebedeaux, Jr. after presentation of "Particulate Pollutants in the Air of the United States" by Messrs. Zimmer, Tabor and Stern at Los Angeles, during the 52nd Annual Meeting. We would like to point out to our readers that although we feel that controversial topics are of great interest, any opinions expressed are those of the individual and are not those of the Association or the editorial staff.

The preceding paper by Arthur Stern and other members of the staff from the Robert A. Taft Sanitary Engineering Center of the U. S. Public Health Service, entitled, "Particulate Pollutants in the Air of the United States," is reported to be a statistical analysis of the results obtained by the National Air Sampling Network. The collection of the original samples was performed jointly by the U. S. Public Health Service and various air pollution agencies and health departments throughout the country. There is no doubt that the system of finding the descriptive parameters for the equations, which would express the characteristics of the plotted curves, is proper statistical methodology. However, because the nature of the samples which were analyzed leaves much to be desired, this procedure does not adequately take into account all of the factors which should be included in a proper analysis.

Several years ago at the Detroit meeting of APCA, a session was held at which Mr. Stern and his staff attempted to answer the questions of various control officials concerning the U. S. Public Health Service's network sampling techniques. While it was agreed that the federal government could supply needed research for the benefit of the local air pollution agencies, there were strenuous objections to the method of reporting these results by the Public Health Service. At that time it was pointed out that even though the results from a given station might be within the standard deviation limits, it did not mean that that particular set of values could be used for an over-all estimation of the contamination covering a relatively large land area. For example, the samples obtained from Houston, Tex., were collected at two stations, one of which is in the downtown area and the other one is at a location in a small municipality around the boundary of the city of Houston. Both of these sampling stations were in such positions that they did not receive a composite exposure to materials which are found along the ship channel and therefore, the results from these stations are of necessity much lower than one would find from sampling other areas of Harris County. So the use of descriptive parameters based on these results is not adequate. At the time of the Detroit meeting, the situation was pointed out to Mr. Stern and both he and members of his staff, which at that time included Dr. Leslie Chambers, had to admit that results of this nature describe only the situation in close proximity to the sampling point. The complaint was also made that the statistical analysis of such figures, expressed to three digits, indicated an accuracy which was not inherent in the sampling procedure. When results of this nature are expanded to predict pollution for the entire Houston area, the inaccuracies are magnified and give an entirely erroneous picture of the true situation. At that time Mr. Chambers stated that the results reported in his paper were statistically correct, but every air pollution officer present felt that his method of reporting his results had caused a considerable amount of disturbance in his local area and, in some instances, had been responsible for the withdrawing of supporting funds. It was asked that the U. S. Public Health Service refrain from using results of this nature as an area-evaluation, and most felt they should not label the results with the name of the city involved. In spite of the objections of the local control groups, the U. S. Public Health Service has continued its policy by reporting such results linked with the name of the city where they were obtained. The present paper carries that procedure to the extreme in that the authors report only the total suspended particulate matter without any qualification, and no attempt is made to code the names of the cities nor to point out that the results obtained are from a very meager sampling of the area and cannot be expected to show the true condition within the area involved.

It is well that we remember that statistical analysis is the use of techniques by which seemingly divergent data are "man-handled" so that straight-line plots are obtained. This is done by various manipulations, such as the use of the arithmetic mean, geometric mean, log scales, ratios, etc. Regardless of how beautiful the plotted results appear, it is not justification for assuming that this same contamination is present in the air a mile away. In the Houston area, for instance, the samples were taken at points where the real pollution contamination could not possibly be sampled because of the prevailing wind directions, and in comparing the suspended particulate matter in the area with that of other areas in the northern part of the country, a very false picture is obtained. The particulate matter in Houston's area is predominantly chemical dusts, while that in other places might be predominantly carbon from improper combustion. One of the sampling points in Houston, at one time, was on the top of a building twelve stories high, but was still close enough to the railroad yards to obtain considerable carbon and soot. On some occasions the content was predominantly cement dust. During the time covered by these samples, that sampling station was changed so that both of these sources are removed from the sampling area. Therefore, the averages which are reported in this paper do not give

(*Continued on page 171*)

TECHNICAL MANUAL ON *Single Retort Underfeed Stokers**

APCA TECHNICAL CO-ORDINATING COMMITTEE TA-6, 1959

Introduction

The Technical Manual for single-retort underfeed stokers has been prepared by the Technical Co-ordinating Committee of the Air Pollution Control Association in co-operation with the Engineering Advisory Committee of the Stoker Manufacturers Association for the purpose of improving performance and reducing air pollution from underfeed stokers.

The recommendations and standards as hereinafter described should be of interest to everyone concerned with the design, installation, and performance of stokers. These standards and specifications should insure comfort, convenience, cleanliness, and economy of operation. Stoker manufacturers, equipment installers, architects, consultants, fuel engineers, and administrative authorities concerned with enforcement of air-pollution ordinances, are provided with basic information which should prove valuable by reference thereto.

Members of the Technical Co-ordinating Committee include smoke and air-pollution enforcement officers, representatives of the Stoker Manufacturers Association, fuel engineers, and other specialists in the field of fuels and combustion. The manual embodies the result of this cumulative experience in the manufacture and application of various coals and equipment.

Section I

Selection and Sizing Criteria

Type of Stoker

Underfeed stokers are classed according to maximum coal burning rate.

The following table is used by the Stoker Manufacturers Association (SMA) and the Bureau of Census.

Class 1	0–60	Pounds of coal per hour, max. burning rate
2	61–100	Pounds of coal per hour, max. burning rate
3	101–300	Pounds of coal per hour, max. burning rate
4	301–1200	Pounds of coal per hour, max. burning rate
5	1201–3500	Pounds of coal per hour, max. burning rate

Underfeed stokers are further classed according to method of removing ash from the fuel bed.

Clinker Type. A clinker-type stoker is considered to be the type whereby ash is normally fused into solid clinker and manually removed from the fuel bed by the use of tongs, hook, etc. It has a solid refractory hearth, or dead plates which may be solid or perforated.

Dump-grate Type. A dump-grate stoker is considered to be the type wherein ash is removed from the fuel bed in granular form by manually or mechanically dumping or tilting the dump grates at intervals. The dump grate is a grate section along one or more outer edges of the grate system, and which is normally in a flat position but can be tilted to allow accumulated ash to drop into an ash pit.

The type of stoker selected depends, in general, on the size required and the type of boiler and load.

The following represents minimum specifications for new plants; in existing boilers certain deviations may be allowed to meet requirements.

Coal Burning Rate	Type Stoker
Less than 200 lb per hr	Clinker type
250–750 lb per hr	Clinker or dump grate
More than 750 lb per hr	Dump grate

Size Selection

SMA Standard Formula

The size of a stoker required for a given installation is determined from a knowledge of the gross Btu load to be handled and the lowest heating value coal generally available to the installation. The following Stoker Manufacturers Uniform Stoker Rating Formula expresses this relationship.

$$\text{Stoker size in pounds of coal (Burning rate per hour)} = \frac{\text{Gross load in Btu per hour}}{\text{Heating value of coal as burned} \times \text{over-all efficiency of stoker and boiler or furnace (expressed as a decimal)}}$$

Gross Load

As noted in Glossary of Terms, gross load is "The peak load to be supplied at the nozzle of a boiler outlet represented by the total of the design load, plus an allowance (called the pickup allowance) for an increase in the normal load due to heating up the cold system." Because of certain differences in the methods of rating boilers in general use, considerable confusion can develop as one attempts to determine the gross load value to use for an installation in a given size boiler. For example ratings of steel firebox boilers or fire-tube boilers are expressed variously in three ways:

1. Net Load†—(SBI Net Rating) which is in terms of sq ft of radiation or Btu's per hour.

2. Design Load†—(SBI Rating) which is approximately 23 1/2% larger than net load (when automatically fired) to allow for normal piping loss.

3. Gross Load†—which is approximately 23 1/2% larger than design load and 50% larger than net load (when automatically fired) to further allow for pickup of load.

Ratings of Cast Iron boilers are expressed as follows: (1) Net Load—(I-B-R Net Rating) which is in terms of sq ft of radiation (steam or hot water) or Btu's per hr. (2) Gross Load—(I-B-R Gross Boiler Output) which is from 56% to 28.8% larger than

* Developed in Co-operation with the **Stoker Manufacturers Association Engineering Committee.**

† See Glossary of Terms for definitions of items 1, 2, and 3.

Table I—SBI (Steel Boiler Institute) Ratings for "Table 1" Steel Boilers[a] (Mechanically Fired)

SBI Net Ratings			SBI Gross Boiler Output 1000 Btu Per Hour	Minimum Heating Surface Sq Ft
Sq Ft Steam Radiation	Sq Ft Gravity Water Radiation	1000 Btu Per Hour		
(1)	(2)	(3)	(4)	(5)
1800	2880	432	648	129
2200	3520	528	792	158
2600	4160	624	936	186
3000	4800	720	1080	215
3500	5600	840	1260	250
4000	6400	960	1440	286
4500	7200	1080	1620	322
5000	8000	1200	1800	358
6000	9600	1440	2160	429
Complete as per Table I, Page 7 of SBI Rating Code				
40,000	64,000	9,600	14,400	2857
45,000	72,000	10,800	16,200	3214
50,000	80,000	12,000	18,000	3571

[a] From SBI Rating Code—File No. 30-C.

Table II—SBI (Steel Boiler Institute) Ratings for "Table 2" Steel Boilers[a] (Mechanically Fired)

SBI Net Ratings			SBI Gross Boiler Output, 1000 Btu per Hour	Minimum Heating Surface, Sq Ft
Steam		Water 1000 Btu Per Hour		
Sq Ft Radiation	1000 Btu Per Hour			
(1)	(2)	(3)	(4)	(5)
275	66	74	99	16
320	77	87	115	19
400	96	108	144	24
550	132	149	198	32
Complete as per Table 2, Page 9, of SBI Rating Code File No. 30-C				
3500	840	945	1260	206
4000	960	1080	1440	236
4500	1080	1215	1620	265
5000	1200	1350	1800	294

[a] From SBI Rating Code—File No. 30-C.

Net Load (when automatically fired). The percentage factor *decreases* as the boiler size *increases.*

Size Stoker to Boiler Gross Output

The gross load for a given installation, and for which the required stoker size is to be selected, can, as a rule be assumed to be equivalent to the gross output ratings of the boiler to be stokered. If the boiler rating is designated in "net rating," "design rating," etc., its gross output rating can be determined in accordance with the previously described correlations between the variously expressed ratings. Tables I and II show these correlations for both steel and cast iron boilers in the sizes covered by this Manual.

High Pressure Boilers

Boilers designed to operate at pressures in excess of 15 psi (as normally used for power and process loads) usually are rated on the basis of one of the following designations:

1. Nominal Boiler Horsepower—based on one horsepower for each 10 sq ft of boiler heating surface. This is referred to as the "nominal" rating.

2. Output Rating. (A) Btu's per hr. (B) Developed Boiler Horsepower (see Glossary of Terms) (C) Pounds of Steam per hr—equals to the heat output of 970.3 Btu per hr.

The above noted empirical basis (No. 1) for rating boilers in terms of "nominal" boiler horsepower is considered obsolete and is unreliable as a means of determining their peak output. Boilers thusly rated, and within the size range covered by this manual, can be operated at ratings from 125% to over 200% of the nominal rating. Therefore, the peak output of boilers rated in this manner must be determined in Btu's per hr, developed boiler horsepower, or pounds of steam per hr. The following will serve as a guide to expected and generally practicable gross output ratings of boilers of various types expressed in terms of percent of nominal boiler horsepower:

1. Firebox or fire-tube boilers—150%.
2. Water-tube boilers with refractory furnace walls—150% to 200%.
3. Water-tube boilers with water-cooled furnace walls—200% to 250%.

Boilers rated on terms of output rating usually can be operated for periods of from two to four hours at ratings up to 110% of the manufacturers "continuous" rating.

Efficiency

Load values shown in the tables included in this manual are based on combined boiler and stoker efficiencies in accordance with the following schedule:

Gross loads up to and including 900,000 Btu per hr (corresponding to 115 lb per hr of 12,000 Btu Coal).....65%
Gross loads over 900,000 Btu per hr and up to and including 12,000,000 Btu per hr (corresponding to 1428 lb per hr of 12,000 Btu Coal)..70%
Gross loads over 12,000,000 Btu per hr.....74%

NOTE: Actually many new modern boilers equipped with efficiency and stoker units and complete control systems will operate at efficiencies up to 78%. If actual design or obtained efficiency is known, it may be used in recalculating outputs.

Explanation of Boiler Ratings Tables

I. Tables I and II for mechanically-fired SBI rated boilers. The Steel Boiler Institute (SBI) rating code for steel firebox boilers designates Table I steel boilers and Table II steel boilers. Table I boilers are defined as those having 129 to 3571 sq ft of heating surface. Boilers covered by this table generally are considered to be in the commercial size classification and are rated on the basis of heating surface with limitations set for grate area, furnace volume, and furnace height.

Table II boilers are defined as those having not more than 294 sq ft of heating surface. Boilers covered by this table generally are considered to be in the residential size classification and are rated from actual tests of oil-fired boilers with limitations pertaining to heating surface and testing conditions. Stoker-fired and gas-fired Table II boilers are rated in accordance with the assigned oil-fired rating. As can be noted by comparing Tables I and II the principal difference between the two rating methods is:

1. Table II rated boilers may be assigned higher ratings for a given amount of heating surface than Table I rated boilers.

2. Table II rated boilers may be assigned a water rating in Btu that is from 12% to 13% higher than the assigned steam rating in Btu.

II. Table I (for SBI Table I boilers).

Table III—IBR (Institute of Boiler and Radiator Manufacturers) Ratings for Cast Iron Boilers (Automatic Fired)

IBR Net Ratings			IBR Gross Boiler Output, 1000 Btu Per Hour
Steam		Water 1000 Btu Per Hour	
Sq Ft Radiation	1000 Btu Per Hour		
(1)	(2)	(3)	(4)
250	60.0		92.9
400	96.0		146.4
550	132.0		198.9
700	168.0		250.7
850	204.0		301.5
1000	240.0		351.8
1150	276		401
1300	312		451
1450	348		499
1600	384		547
1750	420		595
1900	456	482	642
2050	492		689
2200	528	552	736
Complete as per Table 3, Page 413, in Heating and Ventilating Guide			
10,000	2400	2400	3091
12,000	2880	2880	3709
14,000	3360	3360	4328
16,000	3840	3840	4946
18,000	4320	4320	5564
20,000	4800	4800	6182

IBR Booklet Check

NOTE: "Automatic fired" is synonymous with "mechanical fired" of SBI rating table.

(*a*) Column 1 is the SBI Net Rating in sq ft of steam radiation (240 Btu/sq ft).

(*b*) Column 2 is the SBI net rating in sq ft of gravity hot water radiation (150 Btu/sq ft).

(*c*) Column 3 is the SBI net rating in thousand Btu's per hr (240 times column 1 or 150 times Column 2).

(*d*) Should the "SBI Rating" be desired, multiply net rating by 1.235.

(*e*) Column (4) is the SBI gross boiler output rating in thousand Btu's per hr. It equals the SBI net rating in thousand Btu's per hr (column 3) times the factor 1.5.

(*f*) Column 5 lists the minimum heating surfaces Table I steel firebox boilers must have to be assigned the corresponding ratings.

III. Table II (for SBI Table II Boilers).

(*a*) Column 1 is the SBI net rating in sq ft of steam radiation (240 Btu/sq ft).

(*b*) Column 2 is the SBI net rating for a low pressure steam heating system in thousand Btu per hr (240 times column 1).

(*c*) Column 3 is the SBI net rating for a hot water heating system in thousand Btu per hr. These ratings are from 12% to 13% higher than the corresponding ratings in thousand Btu/hr for steam heating systems.

(*d*) Column 4 is the SBI gross output rating in thousand Btu per hr. It equals the SBI net steam rating in thousand Btu per hr (column 2) times the factor 1.5.

(*e*) Column 5 lists the minimum heating surfaces Table II steel firebox boilers must have to be assigned the corresponding ratings even though the test conditions may be met with less heating surface.

IV. Table III (For mechanically-fired IBR rated boilers).

The institute of Boiler and Radiator Manufacturers' Code for rating cast-iron heating boilers is based upon performance obtained during actual tests. The code specifies the number of boilers of a series to be tested, as well as the limitations on the flue gas temperature and analysis, the minimum over-all efficiency, draft loss through the boiler and the heat release. The stoker-fired ratings are based on the Gross IBR Output obtained during the oil-fired tests.

(*a*) Column 1 is the Net IBR Rating for a low pressure steam heating system in sq ft of steam radiation (240 Btu/sq ft).

(*b*) Column 2 is the Net IBR Rating for a low pressure steam heating system in thousand Btu per hr (240 times Column 1).

(*c*) Column 3 is the Net IBR Rating for a hot water heating system in thousand Btu per hr.

(*d*) Column 4 is the Gross IBR Boiler Output in thousand Btu per hr. for steam and hot water heating systems. These are the ratings assigned to a series of boilers as the result of actual test performances under controlled conditions prescribed by the IBR Test Code. The corresponding ratings in Columns 1, 2, and 3 are determined from the Gross IBR Output by applying code specified piping and pickup factors which range from 1.56 to 1.288 for mechanically-fired steam boilers and from 1.333 to 1.288 for mechanically-fired hot water boilers. The factor decreases as the boiler size increases.

Explanation of Stoker Size Selection Table

Table IV is a comprehensive listing of gross or peak boiler outputs in terms of: (1) Btu's per hour. (2) Pounds of steam per hour (from and at 212°F). (3) Developed boiler horsepower. (4) Equivalent Direct Radiation (EDR)—Steam. (5) Equivalent Direct Radiation (EDR)-Gravity Hot Water.

Corresponding coal burning rates with coals of various heating values to develop these ratings are shown. Combined boiler and stoker efficiencies used in the calculations of the burning rates are shown in accordance with explanation under "Efficiency." See Sizing Procedure for use of these tables.

Sizing Procedure

Step 1. Determine gross load.

A. When a new boiler has been selected or when stoker is being selected for a boiler already in service, consult boiler manufacturers catalogue for required boiler rating.

(1) For SBI rated boilers—refer to Table I or II and obtain SBI gross output in Btu's per hr equivalent to the SBI net rating given in manufacturer's catalogue.

(2) For IBR rated boilers—refer to Table III and obtained IBR gross boiler output in Btu per hr equivalent to the net IBR rating given in manufacturer's catalogue.

(3) For Mechanical Contractors Association rated boilers—refer to Table II for steel boilers and to Table III for cast iron boilers and obtain the gross boiler output in Btu's per hr equivalent to the MCA net load recommendation.

B. When the heat loss of the building is the only load data available, multiply the total heat loss in Btu's per hr plus equivalent Btu rating of any domestic hot water equipment to be connected to the boiler, by 1.5 for gross load in Btu's per hr to allow for piping loss and pickup.

C. When boiler to be stokered is to serve a power and/or process load be careful to obtain gross or output rating from a reliable source such as the manufacturer's catalogue or the contract specifications. The rating may be in terms of Btu's per hr, developed boiler horsepower or pounds of steam per hr.

Step 2. Determine Btu value of lowest heating value coal generally available and likely to be used in the installation.

Step 3-Alternate I. Determine stoker size by use of Stoker Manufacturer's Standard Formula.

Step 3-Alternate II. Determine stoker size from Table IV.

A. Locate gross load, or gross or peak boiler output in the column corre-

Table IV—Stoker Size Selection Table

—Gross or Peak Boiler Output— 1000 Btu per Hour	Pounds Steam per Hour	Developed Boiler Horse Power	Square Feet E.D.R. Steam	Square Feet E.D.R. Water	—Pounds of Coal Required per Hour with as Received Btu Value of Coal as Shown Below— 8500	9000	9500	10,000	10,500	11,000	11,500	12,000	12,500	13,000	13,500	14,000
					65% Eff.											
100	103	3.0	417	667	18.1	17.1	16.2	15.4	14.6	14.0	13.4	12.8	12.3	11.8	11.4	11.0
120	124	3.6	500	800	21.7	20.5	19.4	18.5	17.6	16.8	16.1	15.4	14.8	14.2	13.7	13.2
140	145	4.2	583	934	25.3	23.9	22.7	21.5	20.5	19.6	18.7	18.0	17.2	16.6	16.0	15.4
160	166	4.8	666	1,067	29.0	27.4	25.9	24.6	23.4	22.4	21.6	20.5	19.7	18.9	18.2	17.6
180	186	5.4	750	1,200	32.6	30.8	29.2	27.7	26.4	25.2	24.1	23.1	22.1	21.3	20.5	19.8
200	207	6.0	833	1,330	36.2	34.2	32.4	30.8	29.3	28.0	26.8	25.6	24.6	23.7	22.8	22.0
220	228	6.6	916	1,465	39.8	37.6	35.6	33.8	32.2	30.8	29.4	27.8	27.1	26.0	25.1	24.2
240	248	7.2	1000	1,600	43.5	41.0	38.9	36.9	35.2	33.6	32.1	30.8	29.5	28.4	27.4	26.4
260	269	7.8	1080	1,735	47.1	44.5	42.1	40.0	38.1	36.4	34.8	33.3	32.0	30.8	29.6	28.6
280	290	8.4	1170	1,870	50.7	47.8	45.4	43.0	41.0	39.2	37.4	36.0	34.4	33.2	32.0	30.8
300	310	9.0	1250	2,000	54.3	51.3	48.6	46.2	44.0	42.0	40.2	38.5	36.9	35.5	34.2	33.0
320	331	9.6	1330	2,130	58.0	54.8	51.8	49.2	46.8	44.8	43.2	41.0	39.4	37.8	36.4	35.2
340	349	10.1	1420	2,265	61.5	58.1	55.1	52.3	49.8	47.6	45.5	43.6	41.8	40.2	38.8	37.4
360	369	10.7	1500	2,400	65.2	61.6	58.4	55.4	52.8	50.4	48.2	46.2	44.2	42.6	41.0	39.6
380	390	11.3	1580	2,535	68.8	65.0	61.5	58.5	55.7	53.2	50.8	48.7	46.8	45.0	43.3	41.8
400	411	11.9	1670	2,670	72.4	68.4	64.8	61.6	58.6	56.0	53.6	51.2	49.2	47.4	45.6	44.0
420	432	12.5	1750	2,800	76.0	71.8	68.0	64.6	61.5	58.8	56.2	53.8	51.7	49.7	47.9	46.2
440	452	13.1	1830	2,930	79.6	75.2	71.2	67.6	64.4	61.6	58.8	55.6	54.2	52.0	50.2	48.4
460	473	13.7	1920	3,065	84.3	78.7	74.5	70.8	67.4	64.3	61.5	59.0	56.6	54.5	52.5	50.6
480	494	14.3	2000	3,200	87.0	82.0	77.8	73.8	70.4	67.2	64.2	61.6	59.0	56.8	54.8	52.8
500	515	14.9	2080	3,330	90.5	85.5	80.8	76.8	73.3	70.0	66.8	64.2	61.5	59.2	57.0	55.0
520	535	15.5	2170	3,470	94.2	89.0	84.2	80.0	76.2	72.8	69.6	66.6	64.0	61.6	59.2	57.2
540	556	16.1	2250	3,600	97.7	92.3	87.4	83.1	79.1	75.5	72.3	69.3	66.5	63.8	61.5	59.3
560	577	16.7	2340	3,735	101	95.6	90.8	86.0	82.0	78.4	74.8	72.0	68.8	66.4	64.0	61.6
580	597	17.3	2420	3,850	105	99.2	94.0	89.2	85.0	81.2	77.6	74.4	71.4	68.7	66.2	63.8
600	618	17.9	2500	4,000	109	103	97.2	92.4	88.0	84.0	80.4	77.0	73.8	71.0	68.4	66.0
620	639	18.5	2580	4,130	112	106	100	95.4	90.8	86.7	82.9	79.5	76.3	73.4	70.6	68.2
640	660	19.1	2670	4,270	116	110	104	98.4	93.6	89.6	86.4	82.0	78.8	75.6	72.8	70.4
660	681	19.7	2750	4,400	119	113	107	101	96.7	92.3	88.4	84.6	81.2	78.1	75.2	72.5
680	701	20.3	2840	4,530	123	116	110	105	100	95.2	91.0	87.2	83.6	80.4	77.6	74.8
700	722	20.9	2920	4,660	127	120	113	108	103	97.9	93.7	89.8	86.2	82.8	79.8	76.9
750	774	22.4	3130	5,000	136	128	121	115	110	105	100	96.2	92.3	88.7	85.5	82.4
800	826	23.9	3330	5,330	145	137	130	123	117	112	107	102	98.4	94.8	91.2	88.0
850	877	25.4	3540	5,670	154	145	138	131	125	119	114	109	105	101	96.9	93.4
900	926	26.8	3750	6,000	163	154	146	138	132	126	120	115	111	107	103	98.8
					70% Eff.											
950	981	28.4	3960	6,340	160	151	143	136	129	123	118	113	109	104	100	96.9
1000	1040	29.9	4170	6,670	168	159	150	143	136	130	124	119	114	110	106	102
1050	1090	31.4	4370	7,000	177	167	158	150	143	136	130	125	120	115	111	107
1100	1140	32.9	4580	7,330	185	175	165	157	150	143	137	131	126	121	116	111
1150	1190	34.3	4790	7,670	193	183	173	164	157	149	143	137	131	126	122	117
1200	1240	35.8	5000	8,000	202	191	181	171	163	156	149	143	137	132	127	122
1250	1290	37.3	5200	8,330	210	198	188	179	170	162	155	149	142	137	132	128
1300	1340	38.8	5410	8,670	218	206	196	186	177	169	162	155	149	143	138	133
1350	1390	40.3	5620	9,000	227	214	203	193	184	173	168	161	154	148	143	138
1400	1440	41.8	5830	9,340	235	222	211	200	191	182	174	167	160	154	148	143
1450	1500	43.3	6040	9,670	244	230	218	207	197	188	180	173	166	159	154	148
1500	1550	44.8	6250	10,000	252	238	226	214	204	195	186	179	172	165	159	153
1550	1600	46.3	6450	10,330	261	246	233	222	212	201	193	185	177	170	164	158
1600	1655	47.8	6660	10,670	269	254	241	229	219	208	199	191	183	176	169	163
1650	1705	49.3	6870	11,000	272	262	248	236	224	214	205	196	189	181	175	168

sponding to the form in which it is expressed.

B. Read required stoker feed rate under Btu value column corresponding to minimum coal heating value used.

NOTE: Stokers are available only in certain sizes or feeding rates. Therefore, the actual size stoker chosen should be the nearest size above the feeding rate required.

Examples of Determining Stoker Size

I. Small Apartment Building Heating Plant.

Given: (1) A heating load ascertained to be 5600 sq ft of connected steam radiation, maximum.

(2) Domestic hot water load is included in above figure but no consideration has been given to piping loss.

(3) A new steel boiler is to be selected and installed.

(4) Minimum coal specifications list a minimum heating value of 13,400 Btu per pound.

Solution: (1) From boiler manufacturer's catalogue or Table I, it is found that there is available a boiler with an SBI net rating of 6000 sq ft of steam radiation which corresponds to an SBI gross output rating of 2,160,000 Btu's per hr.

(2a) By SMA standard formula

$$\frac{2{,}160{,}000}{13{,}400 \text{ Btu} \times 0.70 \text{ (eff.)}} = 230 \text{ lb of coal per hr (burning rate)}$$

(2b) By interpolating between listed values the same burning rate (230 lb per hr) is found.

(3) The nearest standard size stoker to this burning rate is likely to be 250 lb of coal per hr which would be selected for this installation.

II. Medium size combination heating and process plant.

Given: Existing boiler of 200 hp (nominal rating) watertube type with water cooled furnace walls. Survey indicates possible short peak loads up to 225% of rated capacity. Minimum coal specifications list a minimum heating value of 11,500 Btu per lb.

Solution: (1) Peak output of boiler is 200 hp × 225% = 450 developed hp.

(2a) By SMA standard formula

Table V—Recommended Continuous Maximum Combustion Rates (for 2-Hour Peak Loads, Add 10% to Given Rate)

Type of Stoker	Stoker Size Burning Rate, lb/hr	Maximum Combustion Rate, lb/hr Per Sq Ft Grate Area, lb	Add for Water Cooled Furnaces, lb.[b]
Clinker type with refractory hearth[a]	0–75	10	
	100–200	12	
	250–500	15	
Clinker type with dead plates[a]	0–250	17	3
	300–650	20	3
	750–1200	23	3
Dump grate types			
Screw feed	250–1200	26	3
Ram feed	250–1200	28	4
Ram feed	1300–3500	30	4

[a] Grate area not to be more than 3 times area of retort and tuyere assembly.
[b] These figures apply to water cooled side walls that extend to grate level. Apply pro-rata factor when partial refractory side walls are used.
NOTE: These rates depend on stoker size and type only, and do not vary with Btu value of coal.

$$\frac{450 \text{ hp} \times 33{,}475 \text{ Btu/B.H.P.}}{11{,}500 \text{ Btu} \times 0.74 \text{ (eff.)}} = 1770 \text{ lb of coal per hr (burning rate)}$$

(2b) By interpolating between listed values in Table IV the same burning rate 1770 lb per hr is found.

(3) Nearest standard stoker size to this burning rate would probably be 2000 lb of coal per hr which would be selected for this installation.

Section II

1. Heat Release Rates: (*a*) General. Firing or heat release rates may be expressed either in terms of Btu released per sq ft of grate area per hr or as Btu released per cu ft of furnace volume per hr. It has been found by experience that both have limiting rates under a given combination of fuel characteristics, boiler furnace, and stoker design details and operating conditions. When the limitation governing the maximum practical heat release rate per cu ft of furnace volume for a given installation is exceeded, smoke generally results, and slagging of furnace walls and boiler tubes may occur. In the same manner when the heat release rate per sq ft of grate area is exceeded, clinkering on grates and tuyères may occur and grates may be damaged.

(*b*) Heat Release Per Unit of Furnace Volume. In the consideration of the optimum heat release rate of Btu's per cu ft of furnace volume for a given installation its effect on each of the several pertinent factors present should be evaluated. As it is beyond the scope of this manual to discuss and evaluate each of these several factors connected with furnace volume requirements only recommended maximum heat release rates are noted.

Clinker-type stokers up to and including 100 lb per hr burning rate are allowed a maximum heat release rate of 60,000 Btu per cu ft of furnace volume per hr.

All stokers above 100 lb burning rate are allowed a maximum heat release rate of 48,000 Btu per cu ft of furnace volume per hr.

(*c*) Heat Release Rate Per Unit of Grate Area. As in the consideration of the optimum heat release in terms of Btu's per unit of furnace volume, the optimum heat release in terms of grate area should be selected on the basis of its satisfying the several factors present that are effected by the heat release. Limitations on the scope of this manual preclude a detailed discussion on each of these items. However, the following are especially significant and every heat release recommendation of any value includes due consideration to them: (1) Design characteristics of stoker. (2) Construction and configuration details of the furnace. (3) Analysis of coal to be used:

(*a*) Heating value.
(*b*) Ash content.
(*c*) Ash softening temperature.

Ideally, the heat release rate for a given installation would be in Btu's per hr per sq ft of grate area with correction factors for percent of ash and ash softening temperature. Table V representing the recommendations of the Stoker Manufacturers Association avoids the complications involved with such a detailed evaluation, but gives reasonable consideration to the type and size of the stoker and the furnace wall construction. However, instead of expressing the heat release in terms of Btu per sq ft of grate area, it is expressed as burning rate in terms of lb of coal per hr per sq ft of grate area. Therefore, for a given installation the heat release rate in Btu's per sq ft of grate area would be expected to vary directly with any changes in the heating value of the coals being used.

This method of expressing heat release appears therefore to give no consideration to the ash content of the coal and the softening temperature of the ash. In effect, however, these two factors are partly self-compensating as the ash content of a coal generally varies inversely as its heating value. Although the ash softening temperature is not directly related to the percent of ash, the majority of the lower ash softening temperature coals have higher than average ash contents. Consequently, the use of a maximum burning rate figure will result in lower heat releases in Btu's per sq ft of grate area with lower heating value coals than when higher heating value coals are used. In this way, reasonable compensation is made for the effect of ash content and ash softening temperature.

2. Bridgewalls: Bridgewalls, if installed, shall be for the purpose of confining the fuel bed when grate area would otherwise be excessive. When installed, their height shall be limited to cause the minimum loss in radiant heating surface, and still contain the fuel. This minimum height is usually the normal fuel bed height plus six inches. If overfire air jets are installed in the bridgewall, this height may need to be greater, but must not restrict the flow of combustion gases. In an HRT boiler, good practice is to limit the height so that it does not rise above an imaginary line which runs from the center of the retort (at grate level) to the far end and bottom of the boiler shell.

3. Overfire Air Jets: See Section VI.

4. Stoker Setting: Stokers shall be set so that minimum specifications for furnace volume, grate area, headroom, and furnace draft are complied with. (See Tables VI, VII) It is important to note again that all of these factors are based on the maximum feed rate of the stoker, not on boiler size or load.

In front installations, sufficient clearance must be provided between the boiler front and the stoker hopper so fires can be easily cleaned.

A rear installation is sometimes advantageous and is permissible. With the exception of class 1 and class 2 stokers, side installations should be avoided if at all possible. If necessary to install the stoker from the side, special consideration must be given to clearance between retort and sidewalls, and to provision for completely cleaning the fire. If a side installation of stoker with feed rate of 250 lb per hr or larger is made, a clean-out door (or doors) shall be provided in the side of the firebox opposite the entry of the coal tube, of sufficient size and in such location that fires can be cleaned through this door (or doors). A distance equal to at least the width of the

Table VI—Stoker Setting Specifications (Clinker-Type Stokers)

Stoker Size (Maximum Stoker Burning Rate), Lb/Hr	Minimum Firebox Specifications: Head Room Height, Inches	Grate Area-Square Feet: Ref. Hearth	Ref. Furnace Walls	Water-Cooled Furnace	Furnace Volume, Cubic Feet	Minimum Overfire Draft, Inches of Water
A	B	C	D	E	F	G
15	17.5	1.50	—	—	3	0.042
20	18.0	2.00	—	—	4	0.042
25	18.5	2.50	—	—	5	0.043
30	19.0	3.00	—	—	6	0.043
35	19.5	3.50	—	—	7	0.044
40	20.5	4.00	—		8	0.044
50	21.5	5.00	—	—	10	0.045
60	22.5	6.00	—	—	12	0.046
75	24.0	7.50	—	—	15	0.047
100	27.0	8.33	—	—	20	0.050
150	28.5	12.50	8.82	7.5	38	0.055
200	30.0	16.67	11.77	10.0	48	0.059
250	31.5	—	14.70	12.5	63	0.064
300	33.0	—	15.00	13.0	75	0.068
350	34.5	—	17.56	15.2	88	0.073
400	36.0	—	20.00	17.4	100	0.077
500	39.0	—	25.00	21.7	125	0.087
600	42.0	—	30.00	26.00	150	0.096
750	46.5	—	32.61	28.9	188	0.10
800	48.0	—	34.78	30.8	200	0.10
1000	54.0	—	43.48	38.46	250	0.10
1200	60.0	—	52.17	46.15	300	0.10

For Coals of Other Than 12,000 Btu per Pound as Burned, Multiply Figures in Column F by the Following Factors:

Btu/Lb	Factors	Btu/Lb	Factors
9,000	0.75	11,500	0.96
9,500	0.79	12,500	1.04
10,000	0.83	13,000	1.08
10,500	0.87	13,500	1.12
11,000	0.92	14,000	1.17

firebox must be provided between this door (or doors) and the nearest wall to allow proper use of cleaning tools in the fuel bed.

5. Fire Doors: All fire access doors for clinker type stokers must be so located that a line from the inside lower edge of the opening to the junction of the hearth (or dead plates) and the nearest edge of the retort makes angle of 45 degrees or less with the horizontal.

6. Stoker Pitting: If a stoker is pitted, sufficient clearance must be provided between the sides of the pit outside the boiler and the stoker so that (1) firebed can be cleaned with convenience, (2) stoker can be serviced, (3) coal screw can be removed and (4) flow of air into fan inlet is not restricted. Provision must be made to keep pits free of water.

7. Combustion Air: Outside air for combustion must be provided. This sometimes means providing a special opening from the outside into the boiler room. In such a case; the area of this opening shall be not less than $^3/_4$ of the required chimney area for all boilers installed in the room. Under no circumstances shall a boiler room be ventilated by withdrawing air from the rooms since this would destroy "draft." Combustion air may be introduced into the boiler room by means of a fan, if desired.

8. Down-Draft Boilers: Installation of stokers in down-draft boilers must be considered on an individual basis and approved by the proper authorities.

9. Miscellaneous: Adequate firing tools shall be specified either as part of stoker package or as auxiliary equipment. Maintenance instructions must be supplied on each installation.

Section III

Chimneys and Breechings

Table VIII gives recommended specifications for stacks or chimneys for stokers burning up to 1000 lb/hr. For sizes above this, or for special installations, approval of design must be obtained from the proper authorities.

Breeching shall be as straight and as short as possible. It shall be at least equal in cross-sectional area to the total area of all boiler flow connections leading to it. Additional area up to 20% may be specified to accommodate contingencies beyond average conditions. Adequate provision must be made for any smoke detection equipment, draft control dampers, or other devices needed on the installation. Smoke breeching between boiler and chimney should have properly located clean-outs so that entire breeching is accessible for cleaning.

Whenever possible a fly-ash settling chamber shall be provided at boiler or in the base of the stack; a clean-out door shall be provided in this chamber. Consideration should be given to possible wetting down of the collected fly ash to prevent reentrainment; and to the installation of a gate or damper between the chamber and the stack, for use when chamber is being cleaned. Stack spraying of fly ash is not satisfactory if vacuum removal of collected ash is contemplated.

In every installation, a clean-out door shall be installed in the base of the stack even if no special settling chamber is provided.

Chimney must rise at least four feet above a flat roof and at least two feet above the crown of a peak roof.

Recommended Minimum Stack Sizes

Table VIII is given as a guide to selecting proper stack dimensions. Since draft losses in breeching and through different boilers vary widely, no hard and fast rules can be laid down.

In general, stack size is determined by totalling all draft losses plus overfire draft requires when coal is being burned at the maximum rate, and by similarly determining gas volumes and temperatures under maximum load conditions including an allowance of 25% for leakage.

It is especially important to design stack and breeching for maximum load conditions, not average load, and to use maximum stoker burning rate instead of boiler rating.

Table VII—Stoker Setting Specifications (Dump-Grate Type)

Maximum Stoker Feed Rate, Lb/Hr	Head Room Height, Inches	Minimum Firebox Specifications — Grate Area, Square Feet — Ref. Furnace Walls — Screw Feed	Ref. Furnace Walls — Ram Feed	Water Cooled Furnace — Screw Feed	Water Cooled Furnace — Ram Feed	Furnace Volume Cubic Feet	Minimum Overfire Draft, Inches of Water
A	B	C	D	E	F	G	H
250	31.5	8.6	8.06	7.81	7.20	63	0.064
300	33.0	10.34	9.10	9.37	8.57	75	0.068
350	34.5	12.07	11.30	10.93	10.00	88	0.073
400	36.0	13.81	12.90	12.50	11.42	100	0.077
500	39.0	17.24	16.32	15.60	14.28	125	0.087
600	42.0	20.70	19.61	18.75	17.28	150	0.096
750	46.5	25.86	24.19	23.43	21.43	188	0.10
1000	54.0	33.80	32.64	31.25	28.57	250	0.10
1200	60.0	41.38	38.70	37.50	34.28	300	0.10
1500	60.0	—	45.45	—	40.54	375	0.10
2000	60.0	—	60.60	—	54.05	500	0.10
2500	60.0	—	75.75	—	67.57	625	0.10
3000	60.0	—	90.90	—	81.07	750	0.10
3500	60.0	—	106.06	—	94.59	875	0.10

For Coals of Other Than 12,000 Btu per Pound as Burned, Multiply Column G by the Following Factors:

Btu/lb	Factors	Btu/lb	Factors
9,000	0.75	11,500	0.96
9,500	0.79	12,500	1.04
10,000	0.83	13,000	1.08
10,500	0.87	13,500	1.12
11,000	0.92	14,000	1.17

When induced draft fans are used, their design becomes a special problem and must be judged by the proper authorities.

Marks Mechanical Engineers Handbook is one reference which may be used in designing a stack.

The height of chimney specified in Table VIII will provide sufficient draft for boilers or furnaces with average draft loss through the boiler; for boilers with exceptionally high draft loss requiring chimneys to be specified by manufacturer of boiler higher than those specified in the table, the chimney height specified by the manufacturer shall be required.

Induced Draft Fans

In installations were induced draft fans are provided, the following conditions shall be met.

1. Size of fan shall be based on maximum stoker burning rate.
2. A turn damper shall be installed between boiler outlet and fan inlet.
3. The chimney must rise at least four feet above the top of any nearby buildings. The chimney must rise at least four feet above flat roofs and not less than two feet above the highest ridge. If projections exist on top of building interferring with draft, chimney must be four feet higher than projections.
4. Adequate space must be provided between damper and boiler outlet for installation of smoke detection equipment. Draft and temperature gages when applicable.
5. Fan controls must be properly interconnected with stoker control system. A draft failure cutoff switch to shut down the stoker when induced-draft fan fails to operate; and a time-delay switch to prevent stoker fan from operating until induced draft fan has created proper overfire draft, shall be provided as part of induced draft fan control system.

Section IV

Stoker Coal Specifications

Various factors influence coal specifications for stokers: size, type of boiler and stoker; furnace type and configuration; flame travel; surface (refractory, water cooling); type of grate (stationary or moving, dead plate or dump grate); load characteristics, etc. Coals with caking characteristics may be improved by reducing bottom size.

With the above limitations, the following coal specifications are recommended in Table IX.

Table VIII—Chimney Data

Max. Stoker Burning Rate, Lb Per Hour	Outside Dimensions of fire clay Flue Liner, Inches	Actual Inside Dimensions of Flue Liner, Inches	Actual Area, Sq In.	Inside Dimensions of Round Flue, Inches	Minimum Stack Height, Feet
15	8½ x 13	7 x 11½	81	8	25
30	8½ x 13	7 x 11½	81	8	25
35	8½ x 13	7 x 11½	81	8	30
50	13 x 13	11¼ x 11¼	127	10	30
60	13 x 18	11¼ x 16¼	183	12	35
75	18 x 18	15¾ x 15¾	248	14	35
100	18 x 20	15¾ x 17¼	276	16	40
150	20 x 20	17¼ x 17¼	298	18	45
200	20 x 24	17 x 21	357	20	50
250	24 x 24	21 x 21	441	22	55
300	—	24 x 24	576	24	55
350	—	24 x 28	672	26	60
400	—	28 x 28	784	28	60
500	—	28 x 28	784	28	65
600	—	28 x 32	896	30	65
750	—	32 x 32	1024	32	70
800	—	32 x 36	1152	34	70
1000	—	36 x 36	1296	36	80

NOTE 1: The maximum burning coal rate for the size chimney shown is the burning rate in Column A. For example, for 175 lb coal, use 20 in. x 24 in. x 50 ft chimney.

NOTE 2: Where the boiler manufacturer's chimney specifications are available, the manufacturer's specifications should be used.

NOTE 3: For boilers larger than sizes covered above, refer to boiler manufacturer's specifications.

NOTE 4: Use of an induced draft fan can reduce stack requirements. If one is used, stack must still extend at least four feet above the top of any nearby buildings.

Table IX—Recommended Permissible Size Range

Coal, Lb/Hr	Size	Top	Bottom	Ash	AST °F
0–75	3/4 in. x 3/8 in.	1 in.	10 Mesh	5–8	2000–2500
76–250	1 1/4 in. x 0 in.	1 1/4 in.	30% through 1/4 in.	6–8	2000-up
251–800	1 1/4 in. x 0 in.	2 in.	30% through 1/4 in.	6–10	2000-up[a]
					2300[b]
801–3500	1 1/4 in. x 0 in.	2 in.	30% through 1/4 in.	6–10	2000-up[a]
				6–10	2300-up[b]

NOTE: Dump-grate stokers are considered capable of using coals with varying AST °F. The minimum to maximum available in most markets. Unusual conditions related to the stoker setting, stoker equipment, load characteristics, coal size consist, etc., may dictate slight deviations from the minimum figures noted. As a general rule a given coal in a double-screened preparation reasonably free of fines will burn with a more satisfactory clinkering condition than the same coal containing a high percentage of minus 1/8 in. size in its size consist.

[a] Water-cooled furnaces (steel firebox or water-wall boiler)

[b] Refractory lined furnaces.

Table X—Volume of Overfire Air Recommended

Heating Value of Coal Being Burned, Btu per lb	Volume of Air,[a] cfm per lb of Coal Burned per hr — Light Smoke	Moderate Smoke	Heavy Smoke
11,000	0.18	0.37	0.55
12,000	0.20	0.40	0.60
13,000	0.22	0.43	0.65
14,000	0.23	0.47	0.70

[a] Air quantities at 70°F.

NOTE: 1. Normal design should be based on "moderate" smoke of Table IX. 2. For smoke resulting only from "start-stop" stoker control—use factors under heading "Light" of Table IX. 3. For smoke resulting only from cleaning of small underfeed stokers—use factors "Heavy" of Table IX.

Table XI—Location of Air Jets

Boiler	Preferred Location	Acceptable Location
Steel fire-tube	Bridgewall	(*a*) Tubes for jets may be rolled into water legs
		(*b*) Front wall
Cast iron	Bridgewall	(*a*) Front wall
HRT	Bridgewall	(*b*) Sidewall

Table XII—Number of Overfire Jets Recommended for Various Lengths of Walls and Lengths of Jet Penetration (See note for Jet Spacing)

Length of Furnace Wall Where Jets Installed, Ft	Length of Penetration, Feet 4	5	6	7	8	9	10	11	12	13	14	15
4	9	7	6	5								
5	11	9	8	6	5	5	4	4				
6	13	11	9	8	7	6	5	4	4	4		
7	16	13	11	9	8	7	6	5	5	4	4	3
8	18	15	13	10	9	8	7	6	6	5	5	4
9	21	17	14	12	10	9	8	7	7	6	5	5
10	23	19	16	13	11	10	9	8	7	7	6	6
11		21	18	15	13	11	10	9	8	7	7	6
12		23	20	16	14	12	11	10	9	8	8	7
13			21	18	15	13	12	11	10	9	8	8
14				19	17	15	13	12	11	10	9	8
15					18	16	14	13	12	11	10	9

NOTE: Jets should be equally spaced across the length of the wall. Determine spacing as follows:

$$\frac{\text{Length of wall in inches where jets installed}}{\text{No. of jets + one (1)}} = \text{Jet spacing in inches}$$

Example: Select number of jetsc orresponding to 10 ft length of penetration and 8 ft length of furnace wall (left column): answer is 7 jets.

Thus: $$\frac{8 \text{ ft} \times 12 \text{ in/ft}}{7 + 1} = 12 \text{ in. spacing between jets.}$$

Section V

Basic Stoker Controls

Minimum Specifications

(*a*) 0–500 lb per hr of coal (stoker burning rate): *Steam*—Low water cutoff; high limit pressure control. *Hot water*—High limit hot water temperature control.

Operating Controls

For space temperature control: (1) Thermostat (indoor and/or outdoor type), (2) outdoor type "weather" control.

For constant steam pressure: On-off control actuated by steam pressure.

For constant boiler water temperature: On-off control actuated by boiler water temperature.

Controls for all installations: hold-fire timer; barometric draft damper; manual damper (between boiler outlet and barometric damper).

(*b*) 551–800 lb per hr of coal: Use above specified items, and instead of barometric damper, install modulating-type sequence draft control.

(*c*) 801–3500, lb per hr of coal: Low water cutoff; water level control; windbox pressure gate; furnace draft gage; flue temperature indicator (optional); smoke indicator or recorder; modulating type sequence draft control; modulating type combustion controls.

Section VI

Overfire Jet Systems

Stoker installations burning more than 400 lb per hr of coal each should be equipped with an overfire air jet system. The design of this system should be based on the procedure outlined below which is based on "Application of Overfire Jets to Prevent Smoke from Stationary Plants," published by Bituminous Coal Research, Inc., Pittsburgh, Pennsylvania.

An effective and efficient overfire air jet system for the abatement of smoke requires careful consideration of number, size, spacing, and elevation of the air tubes above the top of the fuel bed; also the capacity of the blower. Furthermore, the header and/or duct that conveys the air from the blower to the tubes should have no sharp bends or abrupt changes in cross-sectional area. When the duct velocity does not greatly exceed 2000 fpm, there will be low pressure drop between blower discharge and air tubes.

Figure 1 shows a sketch of a furance fired by underfeed stoker and lists the essential features which are necessary to realize the two basic objectives of overfire jets: (1) introduce the turbulence and overfire air close to the fuel

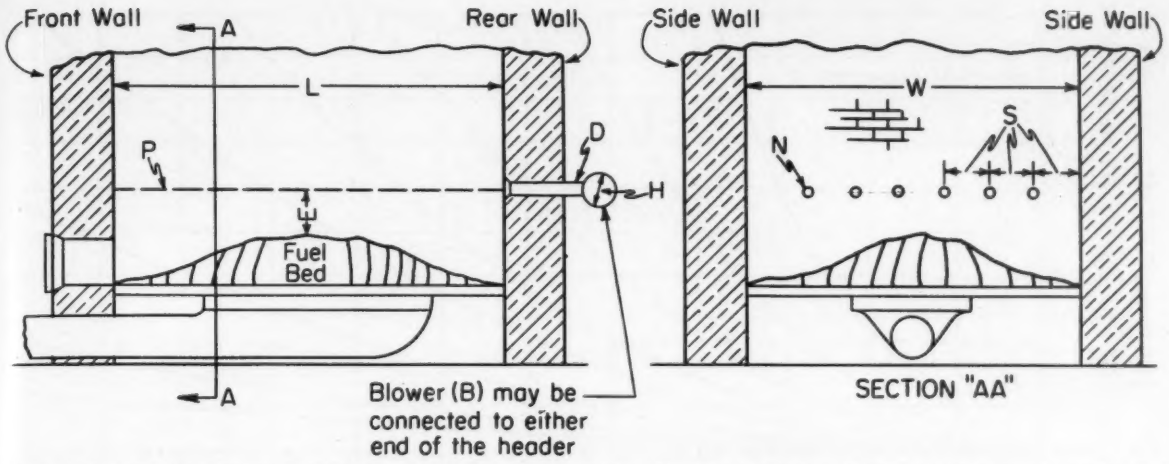


Fig. 1. The essential features for efficient blower jets. (D) diameter of air tube; (S) spacing of air tube; (N) number of air tubes; (E) elevation of air tubes above fuel bed; (H) size of header duct; (B) blower (or fan) capacity; (P) aim air tubes at a point approx 4 in. above top of fuel bed.

bed when the hydrocarbons are released and (2) provide full coverage over the entire fuel bed.

The term "length of jet penetration," as mentioned in this book, means the distance that jets of air must blow to penetrate the smoking areas. Although smoking might be confined to a limited portion of the grate, it is usually best to design the jets for full grate coverage. With this basis of design there is "jet action" available for the entire fuel bed if change in firing practice or coal alters the smoking area.

Basic Data Required for Design of Blower Jets

In order to design modern jets, the following basic information is required.

1. Maximum weight of coal burned per hour.
2. Heating value of coal (approximate Btu per lb as fired).
3. Application condition (see Table I Note).
4. Length of grate.

Design Procedure

Step 1—Blower Capacity

Determine by using the maximum coal burned per hr and Table IX the c.f.m. of overfire air to be supplied by the blower. Max lb coal burned per hr × cfm air per lb coal burned per hr = Blower capacity in cfm.

Step 2a—Jet Location

Determine furnace wall where jets can be most advantageously installed. Table X may serve as a guide.

Step 2b—Jet Elevation

Jets should be installed to point horizontally. The projected jet stream should clear the top of the fuel bed approximately 4 in. This means that the jets will normally be installed 16 in. to 18 in. above the tuyeres.

NOTE: In certain small installations it may be necessary to point the jets slightly above the horizontal.

Step 3—Number of Jets

The number of jets required depends on the jet location (see Step 2a) and the required penetration. Use Fig. 2 to establish these dimensions and use Table XI to determine number of jets.

For stokers 400 to 750 lb per hr of coal where Table XII may not be applicable, use three to seven jets depending upon coal rate and available blower characteristics.

$$\frac{\text{Length of wall in inches where jets installed}}{\text{No. of jets + one (1)}} = \text{Jet spacing in inches}$$

Example: Select number of jets corresponding to 10 ft length of penetration and 8 ft length of furance wall (left column): Answer is 7 jets.

$$\text{Thus: } \frac{8 \text{ ft} \times 12 \text{ in. per ft}}{7 + 1} = 12 \text{ in. spacing between jets}$$

Step 4—Air Per Jet

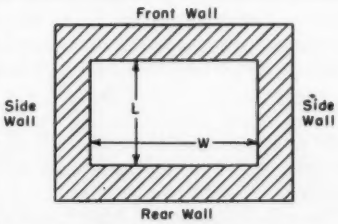
Determine cfm of air to be handled by each jet as follows:

$$\frac{\text{Total cfm air (from step 1)}}{\text{No. of jets (from step 3)}} = \text{cfm of air per jet (air tube)}$$

Step 5—Air Tube Size and Blower Pressure

Determine, by means of Fig. 3, the size of air tube and air pressure required as follows: Locate length of penetration (see Fig. 2) on scale "A" of Fig. 3; proceed vertically upward. Locate cfm of air per jet (from Step 4) on scale "B"; proceed horizontally to the right. When these two lines intersect spot point on nearest size of air tube; proceed vertically to the same tube size in upper set of curves. At this point, proceed horizontally to the left and read air pressure for blower jets on scale "C."

Figure 3 is based on a coefficient of discharge of 1.0. This condition can be realized by providing a bell-mouth entrance from manifold to nozzle pipe as shown in Fig. 4. The simpler system as shown in Fig. 5 has a coefficient of discharge less than unity and the coefficients shown in Table XIII must be used in connection with Fig. 3 in order to obtain "true" flow conditions:



Location of Jets	Length of Ft of—Jet Penetration	Length of Ft of—Wall Where Jets Located
Front wall	L	W
Rear wall	L	W
Side wall	W	L

W = width of grate in feet. L = length of grate in feet.

Fig. 2. Guide for determining length of jet penetration and length of wall where jets are located. When locating jets in the rear wall of underfeed stoker fireboxes use L-1 foot. This will minimize the possibility of flame and gases striking the operator if the front doors are opened with jets turned on. Even with this design—be alert at all times.

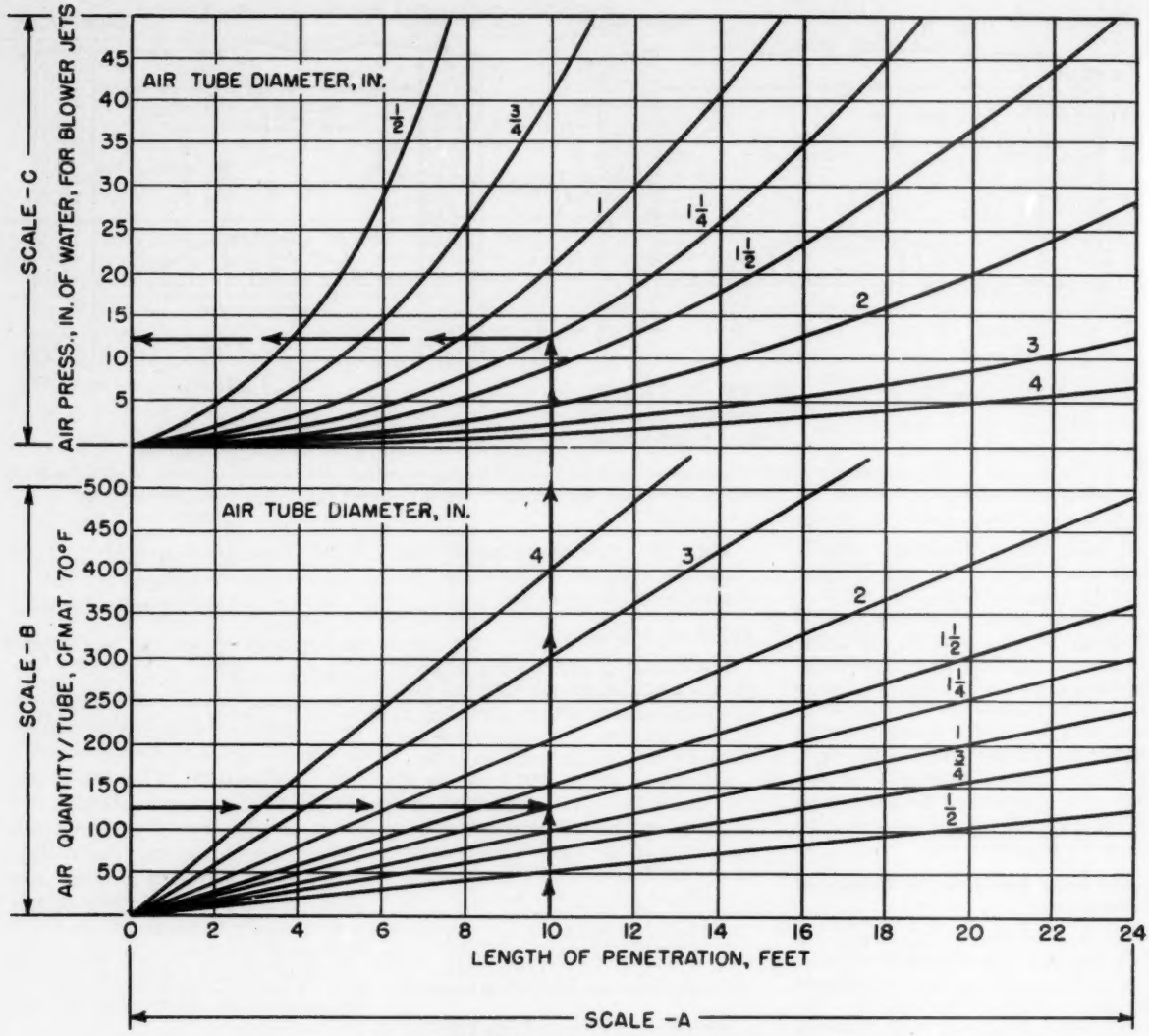


Fig. 3. Calculating size of air tube and air pressure.

Step 6—Duct Size

Determine size of duct between blower and air tubes by means of Fig. 6. Locate air volume of blower (from Step 1) on line "AA," proceed downward to line "BB" where cross-sectional area is shown; proceeding to line "CC" give the diameter of duct having equivalent cross-sectional area.

Method of Control

The following automatic control systems should be used in conjunction with overfire air jets. For maximum burning rate of:

(*a*) 400 to 800 lb per hr of coal: Use time-delay relay (range 0–5 minutes). The time-delay relay is intended to run the overfire system after the stoker stops.

(*b*) 800 to 3500 lb per hr of coal: Use photo-electric controller to operate the overfire air jet system.

Construction of Blower Jets

The air tubes and the header duct may be constructed of standard pipe and fittings. To provide smooth flow of air between blower discharge and air tubes, there should be no sharp bends, abrupt contractions or expansions. This may be accomplished between blower discharge and header duct by locating the blower so that it discharges the air in a straight line directly into the header duct. The air duct between discharge and air tubes should have a cross-sectional area quite close to the size as determined from Fig. 6. Any decrease in duct cross-sectional area will reduce the jet effectiveness.

Smooth flow between header and air tube may be realized by use of one or more reducing couplings as shown in Fig. 4. The diameter of the connecting pipe from header to nozzle must be at least twice the nozzle diameter.

In smaller installations it is usually more practical to construct a system such as shown in Fig. 5. Allowances must be then made for the increased pressure losses as outlined under Step 5 above.

Every effort should be made to provide a duct system and blower located as recommended in the above paragraphs. When necessary to deviate, the blower static pressure should be increased in order to compensate for added pressure resistance in the system. As a guide, add 0.5 in. of water for each 90 deg turn that is incorporated in the duct connecting the blower discharge and header.

If desired, the header duct and air tubes may be constructed of sheet metal with the required stiffening members as suggested by heating and ventiating practice.

Acknowledgments

We gratefully acknowledge the co-

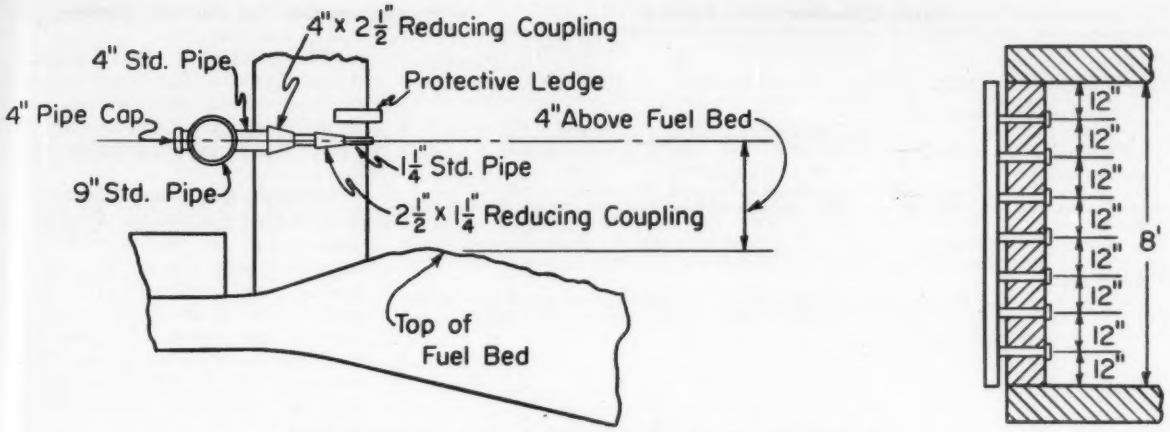


Fig. 4. Cross-sectional views showing typical blower jet assembly in front wall.

operation of the individuals and organizations who worked so diligently in the preparation and compilation of material contained in this manual, and that of the companies represented by the committee for the time and energy they so graciously donated.

We also acknowledge with thanks the co-operation and/or the permission to reproduce material and data from the following sources:

American Society of Heating & Ventilating Engineers; American Boiler & Affiliated Industries; American Society for Testing Materials; Kent's Mechanical Engineers' Handbook—Publishers; Stoker Manufacturers Association; Bituminous Coal Research, Inc.; Bituminous Coal Institute, Inc.

Glossary of Terms

Ash Fusion Temperature: same as "ash softening temperature" (see below).

Ash Softening Temperature: according to the ASTM Standard Method D 271-48, it is the temperature at which a standard cone of ash fuses to a spherical lump. This temperature is approximately related to the likelihood of coal ash to form clinkers.

Base Height: the distance from the floor to the bottom of the water leg on firebox boilers.

Boiler Horsepower: the evaporation of 34½ lb of water per hr into dry saturated steam from and at 212°F. One boiler horsepower is equal to 33,475 Btu per hr. In the table, boiler horsepower ratings are based on gross output.

Burning Rate: maximum coal burning rate of stoker in pounds per hour.

Combustion Rate: pounds of coal burned per hr per sq ft of grate area.

Design Load: the maximum continuous load on the boiler represented by the total of the net load plus an allowance (sometimes called "piping tax") for the estimated heat emission (Btu per hr or EDR) of the piping connecting the radiation to the boiler.

Equivalent Direct Radiation (EDR): a unit of heat delivery either: 240 Btu per hr (EDR steam) or, 150 Btu per hr (EDR water) at standard conditions.

Furnace Volume: the cubical content of the space between the surface of the dead plate and the first place of entry into the gas passages. Where bridgewall is used, the volume above and beyond the top of the bridgewall shall be considered as furnace volume.

Grate Area: the projected area bounded by the furnace walls at the hearth, dump grate or dead plate level. Bridgewall, when used, shall be considered as furnace wall.

Gross Load: the maximum load to be supplied at the nozzle of a boiler outlet represented by the total of the design load, plus an allowance (called the pickup allowance) for an increase in the normal load due to heating up the cold system.

Gross Boiler Output: the maximum quantity of heat available at the boiler nozzle. Generally used when referring to heating boilers.

Head Room: See Setting Height.

Heat Release: the quantity of heat expressed in Btu per hr released in a combustion chamber per cu ft of the furnace volume.

Net Load: (also referred to as Direct Standing Radiation). The standing radiation physically installed and to be heated expressed in terms of sq ft of cast iron radiation. This should include all auxiliary loads such as water heaters, convectors, unit heaters, etc. It does not include any allowance for piping and/or pickup.

Overfire Draft: the draft measured in the combustion chamber of the boiler in inches of water. This is to be measured at a time when the stoker is operating.

Peak Boiler Output: synonymous with gross boiler output. Generally used when referring to power boilers.

IBR Gross Boiler Output: Institute of Boiler and Radiator Manufacturers' rating of a cast iron boiler in terms of the quantity of heat available at the boiler nozzle.

IBR Net Rating: Institute of Boiler and Radiator Manufacturers' rating of a cast iron boiler in terms of the recommended *net load* it will serve and still provide an adequate reserve for normal piping and pickup load.

SBI Net Rating: Steel Boiler Institute rating of steel firebox boiler in terms of the recommended *net load* it will serve and still provide an

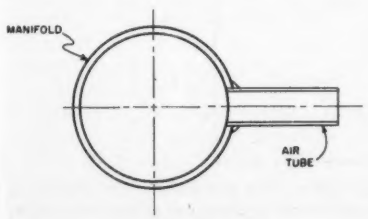


Fig. 5.

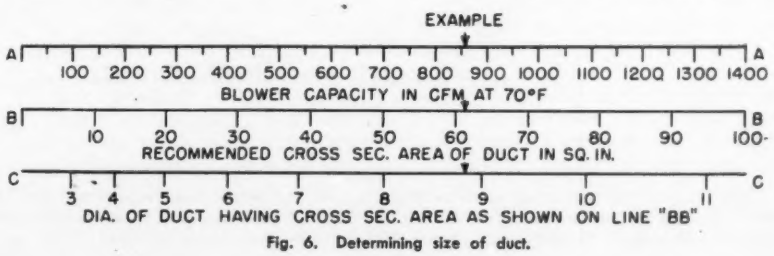

EXAMPLE
A
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400
BLOWER CAPACITY IN CFM AT 70°F
B
10 20 30 40 50 60 70 80 90 100
RECOMMENDED CROSS SEC. AREA OF DUCT IN SQ. IN.
C
3 4 5 6 7 8 9 10 11
DIA. OF DUCT HAVING CROSS SEC. AREA AS SHOWN ON LINE "BB"

Fig. 6. Determining size of duct.

Table XIII—Correction Factors

Entrance Condition	Construction	Coefficient of Discharge	Pressure Factor
Nozzle pipe end flush with inside manifold	Welded or screwed	0.82	1.49
Nozzle pipe end protruding into manifold	Welded or screwed	0.73	1.85

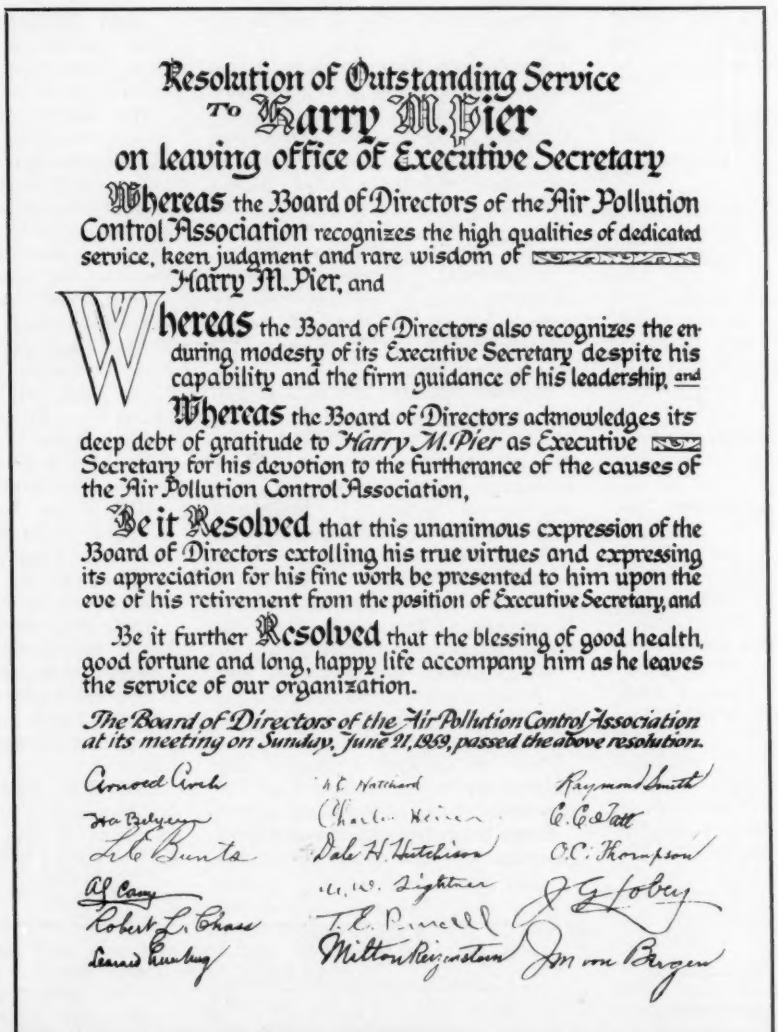
Based on Buffalo Forge Handbook, pages 116 and 131.

NOTE:
1. Coefficient of Discharge: Use when air pressure in manifold and air tubing diameter are given. Obtain true discharge by multiplying air quantity from chart with coefficient of discharge.
2. Pressure Factor: Use when air quantity and air tube diameter (or length of penetration) are given. Obtain required manifold pressure by multiplying air pressure from chart by the pressure factor.

adequate reserve for normal piping and pickup load.

SBI Rating: Steel Boiler Institute rating of steel firebox boiler in terms of the recommended *Design* Load it will serve and still provide an adequate reserve for normal pickup load.

Setting Height (Head Room): the vertical distance from the plane of the dead plates, the hearth surface or the stoker grates to the level of the nearest metal surface or the crown sheet or top of the furnace over the retort of the stoker. In locomotive or single or two-pass firebox boiler, the headroom is the slant distance from the edge of the tuyere blocks (nearest back of firebox) to the lowest row of firetubes.



Resolution of Outstanding Service
To Harry M. Pier
on leaving office of Executive Secretary

Whereas the Board of Directors of the Air Pollution Control Association recognizes the high qualities of dedicated service, keen judgment and rare wisdom of Harry M. Pier, and

Whereas the Board of Directors also recognizes the enduring modesty of its Executive Secretary despite his capability and the firm guidance of his leadership, and

Whereas the Board of Directors acknowledges its deep debt of gratitude to *Harry M. Pier* as Executive Secretary for his devotion to the furtherance of the causes of the Air Pollution Control Association,

Be it Resolved that this unanimous expression of the Board of Directors extolling his true virtues and expressing its appreciation for his fine work be presented to him upon the eve of his retirement from the position of Executive Secretary, and

Be it further Resolved that the blessing of good health, good fortune and long, happy life accompany him as he leaves the service of our organization.

The Board of Directors of the Air Pollution Control Association at its meeting on Sunday, June 21, 1959, passed the above resolution.

Arnold Circh — A.C. Hatchard — Raymond Smith
H.A. Belyea — Charles Heiser — C.E. Tait
L.C. Beaman — Dale H. Hutchison — O.C. Thompson
Al Carey — W.W. Lightner — J.G. Lobey
Robert L. Chass — T.R. Powell
Leonard Greenburg — Milton Reigelman — Jan van Bergen

HARRY M. PIER—For outstanding service to APCA, Harry M. Pier, former executive secretary, was honored by the APCA Board of Directors on June 21, 1959. Mr. Pier has been presented with a beautifully framed, hand drawn copy of this resolution which cites him for his dedicated service, keen judgement and rare wisdom. He resigned his position of executive secretary on July 1.

CRITIQUE of the Article: Effectiveness of ODOR COUNTERACTANTS for the Treatment of STACK GASES

AMOS TURK, PH.D., Consulting Chemist, Danbury, Conn.

On June 4, 1959 Mr. Turk was retained by Airkem Inc. of New York to evaluate the article by M. W. First on "Effectiveness of Odor Counteractants in the Treatment of Stack Gases," which appeared in the May, 1959 *Journal of APCA*, and to extract from it any conclusions which might be important to validation of odor counteractant procedures. The article published herewith is the full text of his report to Airkem Inc.

The Validation of Odor Counteraction Performance

It is the objective of odor counteraction procedures to abate odor nuisances, while simultaneously decreasing the intensities of any perceived odors. When the decrease of odor intensity by counteraction approaches completion, the process is called "odor cancellation."

The evaluation of the efficacy of an odor counteraction performance, therefore, requires a determination of the degree to which the odor nuisances have actually been abated, and the degree to which the intensities of the subject odors have been reduced.

Hedonic Scaling

Referring, first, to "degree of abatement," what meaningful approaches to measurement are available to use? Pilgrim[1] has recently stated that "pleasantness or hedonic tone is the most important characteristic or dimension associated with odors." Mr. First also states that the "pleasantness or unpleasantness of the odor is considered to be a more reliable guide to acceptability by the public-at-large than information on relative odor intensity or any other single odor characteristic." It is, in this regard, difficult to tell what First means when he implies that odor counteraction successes should be supported by "objective, factual data." It is unrealisitc to expect that the nose will ever be "replaced" by an "instrument" which measures hedonic responses to olfactory stimuli. We must recognize that all our scientific information ultimately reaches us by sensory routes. The difference between "objective" and "subjective" data certainly cannot be defended on the grounds that one kind of information is perceptual and the other is not. Pilgrim deplores "the naivete of people who deny their own abilities, who dismiss the evidence of their own senses as 'subjective.'"

If we accept, then, the requirement for hedonic evaluation, we are confronted with several questions: (1) What rating scale may be used? (2) What judges should make the appraisals? (3) Under what conditions should the tests be carried out? With respect to scaling, we must recognize that most of us have many levels of "like" and "dislike." Peryam and Pilgrim[2] have used a nine-point scale, as follows:

1. Like extremely.
2. Like very much.
3. Like moderately.
4. Like slightly.
5. Neither like nor dislike.
6. Dislike slightly.
7. Dislike moderately.
8. Dislike very much.
9. Dislike extremely.

For handling the data, Pilgrim[1] states, "For practical purposes the data are quantified by assigning successive integers to the descriptive categories of the scales and then applying standard statistical techniques."

Mr. First uses simply a two-point scale, as follows:

1. Unobjectionable = pleasant.
2. Unpleasant = objectionable.

Aside from semantic confusion (the prefix un- may denote either good or bad, depending on the word selected, compared with Pilgrim's prefix dis-, which is unequivocal), the scale used by First grossly lacks precision. For example, hedonic improvement of there units on the Peryam-Pilgrim scale, from point nine to point six, would not be indicated at all on the First scale. The possibilities of misleading conclusions from the serious limitations of a two-point scale are obvious.

Selection and Calibration of Judges

The panel of judges which is ultimately relevant to the appraisal of odor nuisance abatement is the affected population itself. This means that a choice must be made between an odor survey by a large segment of the affected population, and the use of a select jury or panel. Both choices have been made at times in the past. The Louisville odor study[5] used segments of the city populace for rating of odor data; past and current work in Cincinnati[6] has also been of the survey type. Pilgrim and his group[1, 2] have used relatively large panels (20 or more) of "randomly selected subjects." Other groups have, of course, used smaller panels. There is little doubt that, in the last analysis, the entire affected population must be the measuring instrument. Even in the field of products so readily predisposed to "objective" evaluations as automobiles, ultimate hedonic appraisal is always the acceptability to the consuming public. For validation of an odor counteraction procedure, then, the ultimate objective, and hence the ultimate measuring guide, must be the cessation of nuisance complaints from the populace. Turk[4] has stated, "The ultimate evaluation of any method of odor abatement must demonstrate the extent to which the adverse effect on people has been controlled." It would be helpful, and no doubt more of such work should be done, to have statistical "before and after" complaint information on a larger scale than has heretofore been collected and reported. Such tasks are undertakings of considerable magnitude and can best be handled by air pollution control agencies which

can collect data in a locality over a period of months or years.

The selection of a small panel to attempt to simulate such an effort is fraught with experimental peril. The most important requirement (and the one usually neglected) is that the panel members be representative of the general reference population in their odor likes and dislikes. An attempt was made at such preference validation by R. Turk.[3] She constructed odor preference orders for 12 selected odorants among a large group of subjects. A smaller "panel" of subjects was then chosen by selecting the individuals whose preference listings most closely typified the overall group preferences.

Mr. First has made no hedonic panel-to-population transfer whatever. The selection of plant employee personnel, and the statement that "their reaction to foul odors would be less intense than that of the population in general" has no statistical basis. It is equally conceivable that individuals who are familiar with an odor are especially alert and sensitive to it.

Presentation of Stimulus

The manner of presentation of the stimulus is no less important than the selection of panel members. In the "real" situation (the one from which complaints initiate) the stimulus may be perceived at unexpected times, and under conditions where the perceiver is otherwise occupied. In the "test" situation the perceivers are, of course, alerted. Data from one situation cannot be automatically assumed, as First has done, to apply to the other. The attendant interpretive problems are elaborated in the next section. In any event, the order of presentation in the test situation should be randomized. First's method of selection of test conditions by the operator, is not statistically valid randomization. It is well recognized that panel members may try to out-guess or anticipate the operator's selection. Therefore, it would be proper to use an impersonal procedure such as selection from a table of random numbers.

Statistical Interpretation

If a panel test cannot duplicate "real" perceptual situations, does this mean that it is useless? Certainly not, but it must be interpreted properly. If conditions are reasonably well controlled, a panel test should indicate whether or not there has been hedonic improvement. In other words, is the "abatement" going in the direction toward increased acceptability? The later conversion to the "absolute" scale of the general population can come only with field experience.

Let us, then, attempt a statistical interpretation of First's data (Table I) to answer only the question: "Has counteraction produced an improvement in odor acceptability, and, if so, with what confidence can this statement be made?" It is useless to ask "how much improvement?" because of the severe limitation of First's two-point scale. We may construct a table to give total number of pleasant responses from his panel when counteraction is used and when it is not. We will apply the "student's t" test to determine the statistical reliability of the difference between the two means obtained.

The data below taken from Mr. First's Table I show that the average number of "pleasant" responses was 4.6 when counteraction was used, and 2.3 when it was not used. Is this difference between the two means statistically significant, and, if so, at what level of confidence? From calculations as shown by Gore,[8] page 33, we obtain a value of $t = 3.05$. The number of degrees of freedom needed for reference to the reliability tables is usually counted as $(N_1 - 1) + (N_2 - 1)$. The value for these data would then be six, and the reliability of difference between the means is about 97%. Because of First's small number of tests, however, especially with no counteraction used, the number of degrees of freedom thus calulated may be unrealistically high. Taking a much more conservative estimate (Gore, footnote on page 32), degrees of freedom are two and the reliability would be about 91%. As an alternate method, from calculations as shown by Youden,[9] we obtain $t = 2.44$ and the reliability of the difference between means is 95%.

Number of "Pleasant" Responses from First's Table I

Experiment Number	Counteraction Used	Counteraction Not Used
1	4	—
2	—	2
3	7	—
4	5	—
5	—	—
6	—	3
7	4	—
8	3	—
N	5	3
ΣX	23	7
$\Sigma X/N$ (mean)	4.6	2.3

If we omit experiment three (First's "counteraction at twice recommended rate") then the two means are $\Sigma X/N_1 = 4$ and $\Sigma X/N_2 = 2.3$. Interestingly enough, the difference between these two means, although smaller than the previous differences, is no less reliable. The value eliminated (seven responses, Experiment Three) is an extreme one which does not add to the reliability of the difference. Using the Gore method with two degrees of freedom, we have $t = 3.15$ and reliability of the difference between means is 92%. From the Youdan method, $t = 2.75$ and reliability of difference is 96%. It is reemphasized that these differences between the means are interpreted only in terms of statistical confidence that the *use of counteraction is preferred over its nonuse.* Attempts to interpret the degree of hedonic improvement would be akin to asking for "how much?" information from "yes or no" data, and therefore no such attempts are made in this critique.

Our interpretation of First's Table I is therefore:

(*a*) No statistically valid statement can be made with regard to the absolute effect on the general population of the treatment method reported.

(*b*) For the panel used, and under the reported conditions of the test, the use of counteractant improves the odor acceptability of the effluent, as compared with the nonuse of counteractant. Reliability of this statement: 91 to 95%

(*c*) For the panel used, and under the reported conditions of the test, the use of no more than a recommended amount of counteractant improves the odor acceptability of the effluent, as compared with the nonuse of counteractant. Reliability of this statement: 92 to 96%.

Intensity Scaling

We may now consider the second aspect of counteraction: reduction of odor intensity. The primary measurement approaches reported by workers in the field have been intensity scaling,[1, 2] (e.g., none, slight, moderate, strong, extreme) and the Beck[7] method of psychophysical scaling, in which odor intensities are related to a material concentration series. First's Table II presents the subjects' estimates of *material* emission. This type of information is entirely irrelevant to the evaluation of the intensity reduction feature of a counteraction process. It is, furthermore, entirely misleading in its implication that material quantities of odorant can be gauged by smell impressions directly; logarithmic relationships are generally accepted as more applicable. Finally, it is inappropriate in view of the fact that material determinations of this kind are now carried out by instrumental methods. The best statement that can be made is:

The data of First's Table II are irrelevant to hedonic or intensity scaling and hence irrelevant to the appraisal of the efficacy of the counteraction method used.

Summary and Conclusions

A technical appraisal of an air pol-

lution abatement method should be logical in its objective, methods, and interpretation. An attempt has been made to extract from Mr. First's paper those conclusions which are relevant to the validation of the two objectives of an odor counteraction procedure: hedonic improvement and reduction of odor intensity. The interpretation of First's data relevant to these objectives, follows:

1. No statistically valid statement can be made with regard to the absolute effect on the general population of the treatment method reported.

2. For the panel used, and under the reported conditions of the test, the use of counteractant improves the odor acceptability of the effluent, as compared with the nonuse of counteractant. Reliability of this statement: 91 to 95%.

3. For the panel used, and under the reported conditions of the test, the use of no more than a recommended amount of counteractant improves the odor acceptability of the effluent, as compared with the nonuse of counteractant. Reliability of this statement: 92 to 96%.

4. The data of First's Table II are irrelevant to hedonic or intensity scaling and hence irrelevant to the appraisal of the efficacy of the counteraction method used.

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Index to Advertisers

Aerotec Industries, Inc.	125	Hemeon Associates	168
Beckman Instruments, Inc.	Back Cover	Lauren B. Hitchcock Associates	168
Beckman & Whitley Inc.	Inside Front Cover	Pangborn Corporation	171
Buell Engineering Company, Inc.	173	Research Appliance Company	128
Buffalo Forge Company	126	Research-Cottrell, Inc.	175
Day Company	170	The Staplex Company	176
Ducon Company, Inc.	174	Western Precipitation Corporation	Inside Back Cover

An AUTOMATIC Atmospheric FLUORIDE ANALYZER

With Potential Application to Other Pollutants

DONALD F. ADAMS, ROBERT K. KOPPE, and **HOMER J. DANA,**
Industrial Research Division, Washington State Institute of Technology,
State College of Washington, Pullman, Washington

Introduction

Complex problems are involved in sampling air pollutants. Variables such as meterorological conditions, topography, rates of pollutant emission, gas phase chemical reactions at low concentrations in the atmosphere with or without ultraviolet radiation, etc., make it desirable to use automatic sampling and measuring devices for the determination of the ever-changing pollutant levels in the atmosphere. Many instruments for the analysis of gaseous pollutants have been developed because of this need.

Sulfur dioxide was one of the first pollutants for which instrumentation was developed. Thomas and co-workers[18–22] based their Autometer upon a measurement of the change in electrolytic conductivity of a dilute sulfuric acid-hydrogen peroxide solution in which absorbed SO_2 was oxidized to the sulfate ion. They adapted the Autometer for continuous determination of CO_2 in the atmosphere.[21]

The Titrilog absorbs SO_2 in an acidic bromide solution in which a constant low level of bromine is electrolytically generated. Absorbed compounds which are oxidized by bromine are titrated to a potentiometric endpoint. The resulting reduction in bromine level is sensed by an appropriate electrode system and additional bromine is then generated to maintain the original bromine concentration. The current required to generate this additional bromine is a measure of the SO_2 present in the atmosphere.

Katz[13] described another method for the automatic determination of SO_2 in the atmosphere. His instrument involved a photometric measurement of the fading of the blue color of a starch-iodine solution in the presence of the reducing gas.

None of these instruments are specific for SO_2. The Autometer will also record other soluble, ionizable gases in the sampled air stream. The Titrilog measures other reducing gases such as H_2S, mercaptans, and unsaturated hydrocarbons. The starch-iodine method is less subject to interference from H_2S than the Titrilog since neutral iodine is less reactive than bromine.[14]

A continuous analyzer has been developed for H_2S employing reflectance measurements from a lead acetate-impregnated tape.

Oxidant recorders have been developed which measure, either colorimetrically or electrometrically, the amount of iodine liberated from buffered potassium iodide solutions.[10,15] Oxidant levels have also been determined colorimetrically through the oxidation of phenolphthalein solutions.[12]

The Austin dual recording colorimeter[8] for oxidants embodies two colorimeters, one to measure color changes in a phenolphthalein reagent and the other to measure a ferrous thiocyanate reagent. Air is sampled at a fixed rate through a measured volume of reagent for a set sampling period. Readings of the transmittance of the reagents are automatically made and recorded before and after each sampling period.

Thomas, et al.,[22] recently described the application of a modified Greiz-Saltzman reagent for the automatic analysis of oxides of nitrogen in the atmosphere. A California company has marketed an analyzer which permits colorimetric analysis of the atmosphere for oxides of nitrogen and oxidant and conductivity measurements of SO_2 levels in a single instrument. Separate gas flow panels are available for each pollutant and may be mounted within a single metal enclosure. Recordings are made in a multi-channel recorder. A monetary saving over buying three separate instruments for the three pollutants is claimed by the manufacturer.

A laboratory model of an automatic analyzer for HF has been described by Chaiken, et al.[9] The method is based on the selective quenching of the fluorescence of magnesium oxinate by fluoride ions.[14] The contaminated air is drawn through a filter tape on which the fluorescent compound is impregnated. Changes in fluorescence are measured photometrically. This instrument is not available commercially.

Adams, et al.,[5] presented a preliminary description of laboratory bench model of a versatile, automatic analyzer for atmospheric fluorides and SO_2. The design of the instrument should permit its use in the determination of other pollutants for which colorimetric methods of analysis are available.

The constructional details of most commercial and laboratory analyzers virtually preclude simple conversion of a given instrument to the analysis of a pollutant other than the one for which it was designed. For most applications it is necessary to obtain a different instrument for each pollutant to be determined, thus contributing heavily to the expense of conducting air pollution surveys.

Another problem frequently encountered in air survey work concerns the wide range of concentrations of pollutants which exist in the atmosphere from time to time. Direct recording over such an enormous range may be difficult at times. However, it would be rather simple to record *time* as a single function of a pollutant exposure period. The measurement of the concentration of air pollutants in terms of the time required to accumulate a standard concentration of the pollutant is known as *dosimetry*. An analyzer designed as a dosimeter would utilize a relatively inexpensive time-date stamp to record the varying lengths of time required to accumulate equal pollutant concentrations. This procedure would eliminate the necessity for more expensive, continuous potentiometric recorders. In addition, the record produced would be of a concise nature, recording only as the pollutant concentrations rise to significant levels. In contrast,

continuous recording instruments produce great lengths of chart paper which must be inspected in order to discover the relatively short periods showing significant pollution.

A versatile, dosimeter-type instrument was designed which would (a) have potential application for the automatic determination of any pollutant for which there is a colorimetric analytical method and (b) record time required to accumulate standard concentrations of a given pollutant. It is believed that the instrument could be produced at a reasonable price, would yield significant data concerning the changing levels of atmospheric pollutants, and wide application in the study of a variety of gaseous pollutants in stacks and in the field.

In addition, the contracting agency stipulated that reagents for the determination of SO_2 and HF be developed for use in instrument. Only the work involving the analysis of fluorides is presented in this paper. The procedure used for SO_2 is based on the work of Katz[13] which has been applied to the automatic analysis of SO_2 in the atmosphere.

The prototype instrument, a two-channel analyzer permitting simultaneous determination of SO_2 and HF, embodied both dosimeter and continuous recording features. Continuous recording was found to be necessary while developing suitable specific reagents for use in the instrument. Instantaneous and continuous observations of the reaction of the reagent in the analyzer under varying operational conditions greatly facilitated the process of reagent study. Operating models of the analyzer could easily be constructed in either the dosimeter or continuous recording form, depending upon requirements.

Description of Equipment

Two separate prototype analyzer units were constructed and assembled within a single metal enclosure to permit convenient, simultaneous development and field testing of reagents for the determination of SO_2 and HF in the atmosphere. Each versatile analyzer consists of two fundamental components: (a) a colorimeter capable of either triggering a time stamp upon development of a pre-selected photocell output equivalent to some concentration of the pollutant which has been absorbed in the reagent (dosimeter model) or driving a recorder (the continuous recording model) and (b) an air-reagent contacting system in whihc a continuously circulating volume of reagent contacts a sampled air stream until a pre-selected concentration of the desired pollutant has been absorbed by the reagent. The additional equipment making up the analyzer permits these fundamental components to carry on their function in an automatic manner. The complete schematic flow diagram of this versatile analyzer is shown in Fig. 1. The assembled analyzer is pictured in Figs. 2 and 3. No consideration was given to minimum size or weight of components in the construction of these prototype analyzers. Subsequent models can be assembled in a readily portable package.

One of the colorimetric systems consisted of a Photovolt Model 501-M fluorescence photometer. This unit was slightly modified to permit continuous flow measurements. In addition, a removable 45° mirror was installed to make possible transmittance measurements in the ultraviolet and visible light ranges. This photometer also includes four ranges of amplification to permit increased sensitivity when required. A wide choice of analytical methods is afforded because of the versa-

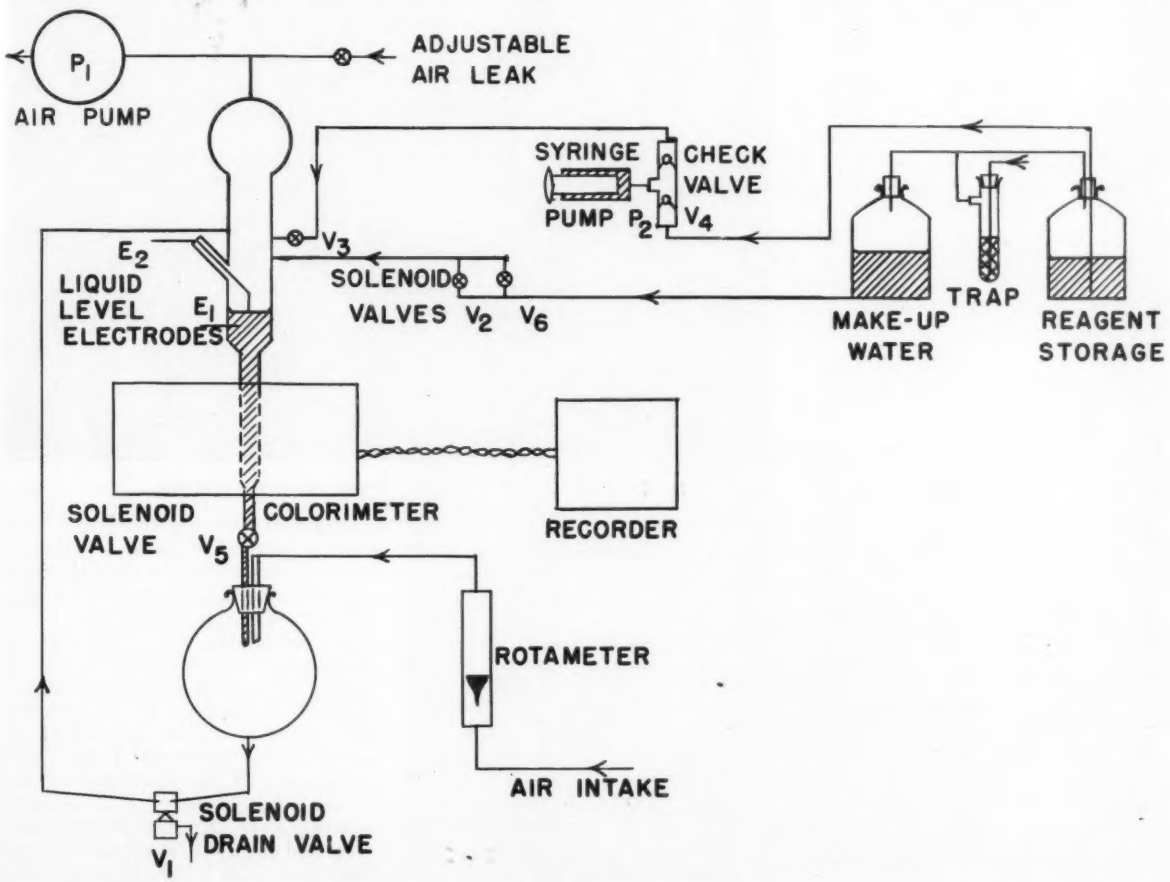

Fig. 1. Schematic diagram of versatile, automatic air pollutant analyzer.

tility of this modified photometer.

The second analyzer utilized a Photovolt Model 400-S continuous flow photometer. Without extensive modifications this instrument is limited to measurements of visible light absorbance. Its use, however, greatly reduced constructional costs and would undoubtedly be adequate for many applications.

A Hanovia S-4 mercury vapor light, connected to the power source through a Sola constant voltage transformer, is used as the light source with the Model 501-M photometer. A G. E. germicidal lamp, mounted in an interchangeable housing, may be easily substituted for the S-4 lamp when conducting measurements requiring short ultraviolet radiation of 2567 A.

A 50 w projection lamp, connected to the power source through a Sola constant voltage transformer, provides the light source for the Model 400-S photometer. Although it has been reported that these lamps have a relatively short life, this type of lamp has given uninterrupted service for periods exceeding nine months under the existing operation conditions to be described later.

Both photometers are constructed to permit easy interchange of optical filters, thus providing a selection of wave bands of light suitable for use with the analytical reagents utilized. The model 501-M also provides for insertion of a secondary light filter to block scattered ultraviolet light when the unit is operating as a fluorometer.

For dosimetry, the output voltage of the colorimeter is utilized to operate a time stamp by changing the grid voltage on a sharp cut-off triode normally biased beyond cut-off. A double throw switch permits the time stamp to be operated when the photometer output reaches either a pre-selected maximum or minimum (Fig. 4). This arrangement would produce a tape record consisting of a line entry of the minute, hour, day and year at which each pre-selected dosimeter concentration of the desired pollutant was attained. Subtraction of each preceding time record from its following record provides the actual air sampling time involved in each dosimeter cycle.

In the continuously recording version, the output from the photometer was hooked across a separate voltage divider to provide a 50 mv full scale signal to the Leeds and Northrup 0-50 mv recorder.

A concurrent type of air-reagent contacting system was designed to facilitate continual circulation of a small batch of reagent through an optical flow cell with a minimum of auxiliary equipment. A detailed drawing of a typical contractor system is shown in Fig. 5. Air sampling rates between a few hundredths of a cfm to max of 1 cfm may be selected by proper adjustment of an air leak valve on the air pump.

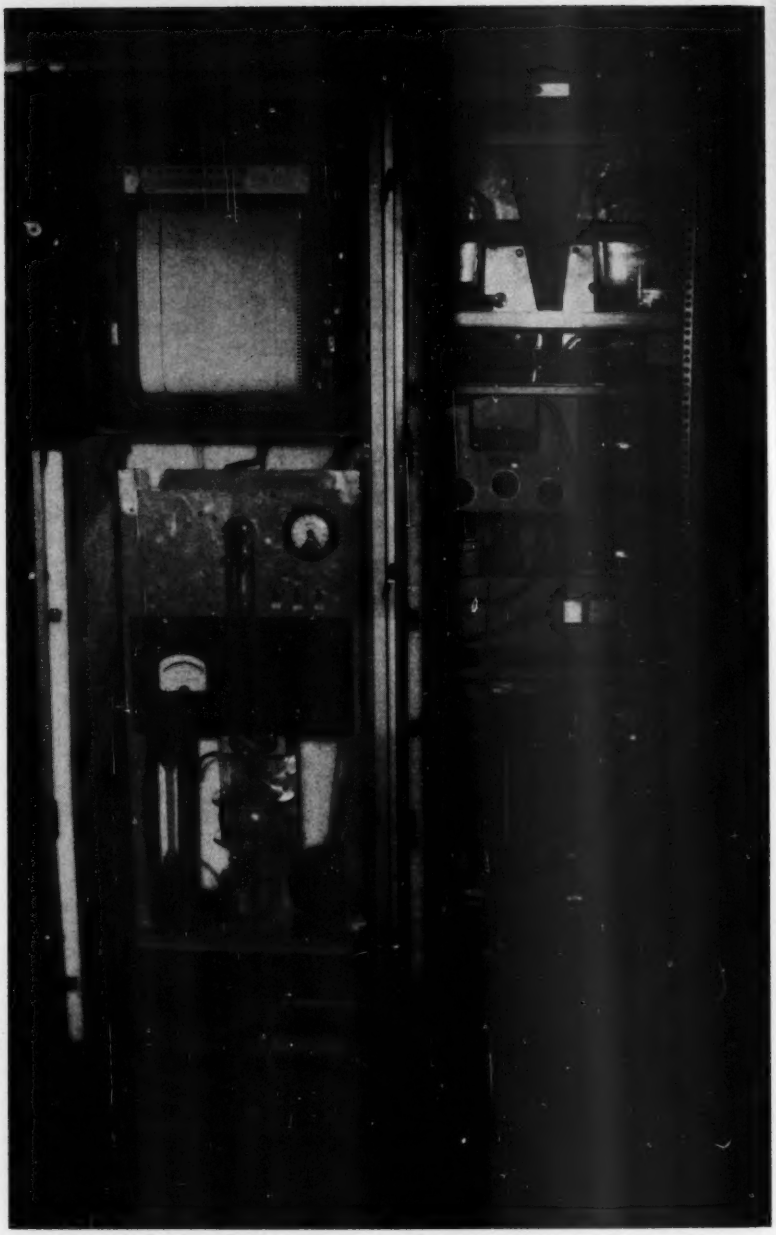

Fig. 2. Interior view of "Universal" air pollutant analyzer.

The sampled air stream was drawn through a rotometer mounted on the face of the analyzer. The air flow was regulated by means of a built-in, adjustable, air leak of the vacuum side of the Fisher air pump (P_1, Fig. 1). Air entering under suction lifts the reagent, which has fallen by gravity through the optical path, up through the contacting column. The scrubbed air passes out through the exhaust tube at the top of the system to the suction pump and the reagent drains back through the optical path. A constant head of reagent was maintained within the optical cell by means of the capillary tip at the lower end of the cell.

A dosimeter-type instrument necessarily cycles a small volume of reagent for varying lengths of time. Continual changes in humidity of the sampled air stream as well as the rate of air sampling will produce a variable and continued reduction in reagent volume through evaporation. Such volume changes would produce an unwanted increased light absorbance readings by the photometer. Therefore, an electronic liquid level control system[2]

was designed to sense slight decreases in reagent volume within the air-reagent system and to maintain the reagent at its initial volume by injection of make-up water as required. Reduction in reagent level is sensed by a suitable electrode system, Fig. 5. Interruption of the electrode-reagent circuit activates the electronic control circuit, Fig. 6. Small increments of make-up water from the water storage bottle are introduced through a Beckman "Titrimeter" valve (V_6, Fig. 1) as required by the rate of liquid evaporation.

A motor-operated, 2-min, single cycle, multiple cam timer switch controls the sequencing of the various automatic operations of the analyzer during the reagent changing cycle. Table I indicates the timing of a typical reagent cycling operation.

The cycling of the reagent with the stream of continuously sampled air continues until either (a) a pre-selected concentration of the desired pollutant is accumulated, (b) a maximum time is reached over which the reagent remains stable in the presence of a circulating stream of unpolluted air, or (c) the reset button is manually operated. A reset time delay relay is set to control the maximum cycling time of a given charge of reagent. In the absence of the desired pollutant, the air sampling cycle will continue until this maximum time has elapsed. The time delay relay will activate the reagent change cycle and reset itself to the maximum time. Should the desired, pre-selected pollution concentration be attained during a lesser time interval, the attainment of this level will activate the reagent change cycle and simultaneously reset the relay to maximum time. Similarly, pushing the reset button at any time will cause the reagent to be changed and reset the timer relay to maximum time. In the continuously recording model, an adjustable cam was mounted on the potentiometer slide wire shaft of the recorder which closed a micro-switch upon attainment of the pre-selected photometer output. Closing this micro-switch magnetically activated the multi-cam timer controlling the reagent change cycle as described under condition (a) above.

Table I—Sample Changing Sequence

Time, (Seconds)	Operation
0	Recorder shut off
0	Air pump turns off
0	Dump valve opens
30	Dump valve closes
30	Rinse water turns on
35	Rinse water turns off
35	Air pump turns on
40	Air pump turns off
40	Dump valve opens
70	Dump valve closes
70	Reagent syringe pump turns on
100	Reagent injection completed
100	Air pump turns on
120	Recorder turns on

Reagents

Selection of suitable reagents for the determination of pollutants in the atmosphere in a dosimeter type analyzer must be based on the following criteria:

1. Good sensitivity in the expected concentration range.
2. Conformity to Beer's law within the limited concentration range expected.
3. Nonsensitivity of the reagent to the expected concentration of the other ion-producing pollutants, frequently found in association with the pollutant being determined.
4. A minimum time required for the reaction to attain equilibrium.
5. Reaction stability at equilibrium.
6. Low temperature coefficient.
7. Stability of the prepared reagent.
8. A high buffering capacity with relative insensitivity of the color reaction to small changes in pH.

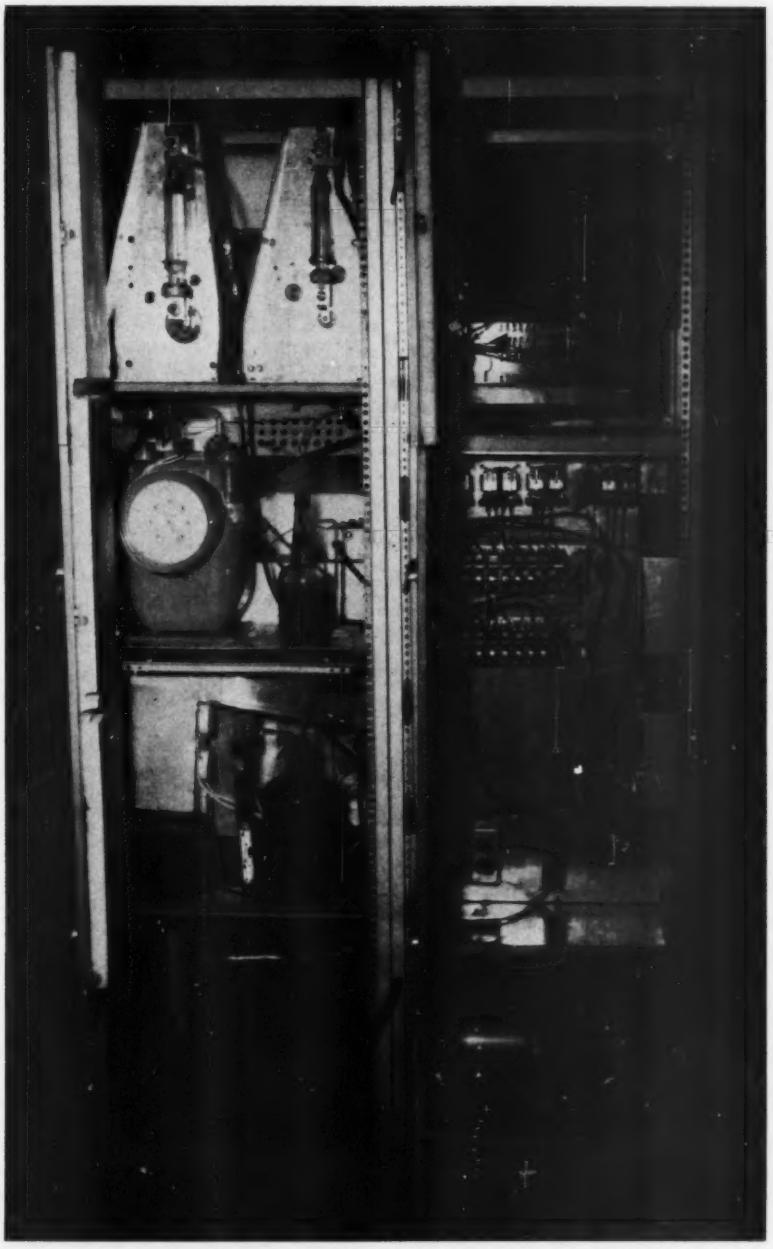

Fig. 3. Interior view of "Universal" air pollutant analyzer.

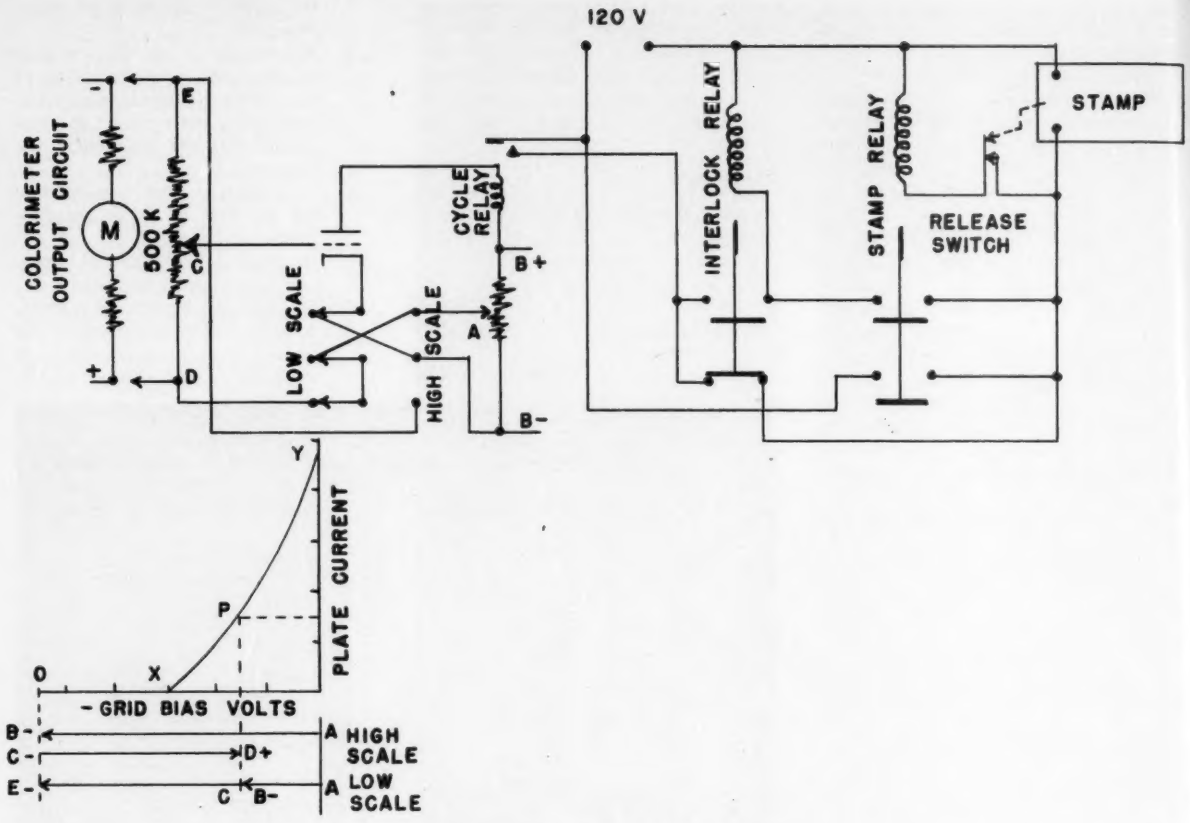

Fig. 4. Circuit for colorimeter operation of a time-stamp.

Hydrogen Fluoride

Study of many published analytical procedures for the fluoride ion revealed two methods conforming to most of the above ideals. The Zirconium-Eriochrome Cyanine R Lake method of Megregian[16] appeared to meet all but requirement number eight. It was later shown that the reduction of HCl resulting from continued aspiration of the reagent up to 24 hr did not significantly change the color of the reagent.[4]

The Aluminum-Superchrome Garnet Y method of Powell and Saylor[17] measured up to most of the requirements, but failed tests four and eight. Substitution of a nonvolatile buffering system for the Powell Saylor acetic acid-acetate buffer eliminated objections to number eight. The literature indicates that equilibrium is attained in 90 min at room temperature and in 5 min at 140°F. Successful application of this method might necessitate operation of the air-reagent contact system within the temperature range of 120–160°F. to reduce the time required for the reagent-fluoride system to attain equilibrium. Experience in the operation of our air-reagent contactor at 120°F indicated that excessive loss of reagent through the rapid drying of spray droplets on the hot side-walls of the contactor may make the use of such elevated contractor temperatures impractical.

The Megregian reagent was modified through a 50% reduction in the concentration of HCl used. This decrease in acidity resulted in a significant increase in the fluoride sensitivity with no noticeable change in SO_2 interference, time required to attain equilibrium, color change produced by aeration loss of HCl, etc.

A further modification of the reagent was necessary to retard the air oxidation of the aerated reagent. Hydroquinone and dimethyl octynediol are the most satisfactory stabilizers found to date. Further study of reagent stabilizers should be made. Successful extension of this search would permit longer periods of sampling with each injection of reagent, thus more nearly approaching the ideal dosimeter reagent. The present reagent is however, adequate for application in a dosimeter, if the reagent cycling cycle is limited to a max of 24–48 hr.

The light absorbance measurements are conducted with Zirconium-Eriochrome Cyanine R reagent using the Hanovia S-4 mercury vapor light and a narrow band pass optical filter peaking at 550 μ. Fig. 7 shows the spectral characteristics of the modified reagent and the reagent + 20 μg of added fluoride. A sensitivity of approximately 1% T/μg F^- is observed in the 0–30 μg range at 550 μ.

Reagent Preparation

Stock Dye Solution. Dissolve 1.800 g of Eriochrome Cyanine R. in distilled water and dilute to 1 l.

Acidified Zirconium Stock Solution. Dissolve 0.1308 g zirconium hydroxide in 375 ml of warm concentrated HCl

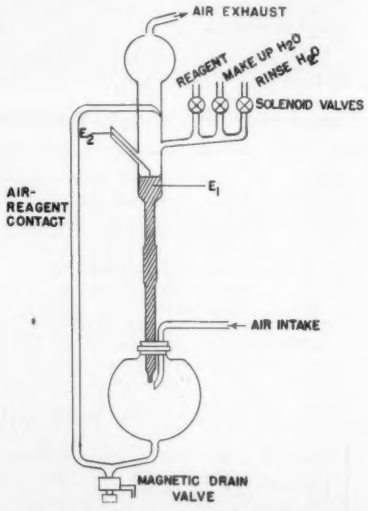

Fig. 5. Air-reagent contactor detail.

(sg 1.19), cool and dilute to 1 l with distilled water.

Fluoride Reagent. To 500 ml of distilled water, add 200 ml of the acidified zirconium solution followed by 200 ml of the dye solution. Then add 3.00 g Surfynol 82. Dilute to 1 l. Two drops of Dow-Corning Antifoam A Emulsion is then added to control foaming.

The prepared reagent is then transferred to a 1 l storage bottle in the atmospheric analyzer and protected from the air with an alkaline pyrogallol trap. The reagent has been found to remain stable for periods up to several weeks.

A series of analyses were conducted in which samples of test chamber atmosphere (in the 0–5 ppb F^- range) were drawn through two independent fritted glass scrubbing towers at a rate of 1 cfm. The absorbing liquid was 150 ml of 0.01 N NaOH. The volume of air passing through each tower was measured with dry test flow meter. The fluoride content of the absorbing liquids was determined by thorium nitrate titration.[6] The sampling procedure has been previously described.[7]

A second comparison was then made between atmospheric fluoride concentrations found with a scrubbing tower and the automatic analyzer. Table II records the statistical evaluations of the reproducibility of analysis of HF atmospheres in a test chamber using (a) duplicate scrubbing towers and (b) a scrubbing tower vs the automatic fluoride analyzer. These data indicate that there is no statistical difference in the error of measurement between methods (a) and (b) above. The variation associated with the comparison of single scrubbing tower samples with the ADAK values is somewhat greater than the standard error associated with the analyses obtained from duplicate scrubbing tower samples. This variation, however, is not significant at the 5% level.

Table II—Statistical Comparisons of Manual and Instrumental Methods of Air Analysis

Source of Variation	Standard Error of Estimate	No.	F Ratio	Value of F for 5% Significance
Duplicate scrubbing towers (a)	0.55 ppb HF	14	—	—
Scrubbing tower vs ADAK (b)	0.82	11	—	—
(a) vs (b)	—	—	2.22	2.67

Figure 8 shows typical curves obtained with the recording fluoride dosimeter on laboratory test atmospheres of HF (Fig. 8a), SO_2 (Fig. 8b), and filtered air (Fig 8c), and in the field (Fig. 8d) during a time when simultaneous injury was produced in exposed Ethyl Cave Cole gladioli. Figure 8d, however represents only a portion of the total recorded fumigation period which produced the observed leaf burn.

Figure 9 shows a calibration curve obtained with the automatic analyzer by the addition of 0.30 μg F^- to 25 ml of the reagent. Atmospheric concentrations of fluoride in terms of part per billion HF may then be calculated for any desired time span during a given reagent cycle by dividing the micrograms of fluoride found by the cubic meters of air sampled during the selected study period. In practice, Fig. 9 would be reproduced on a clear plastic sheet on a scale equal to the recorder span and placed over the record of each cycle. The accumulated fluoride between any two points on the record can be readily determined in this manner.

Performance and Results

The assembled two-channel instru-

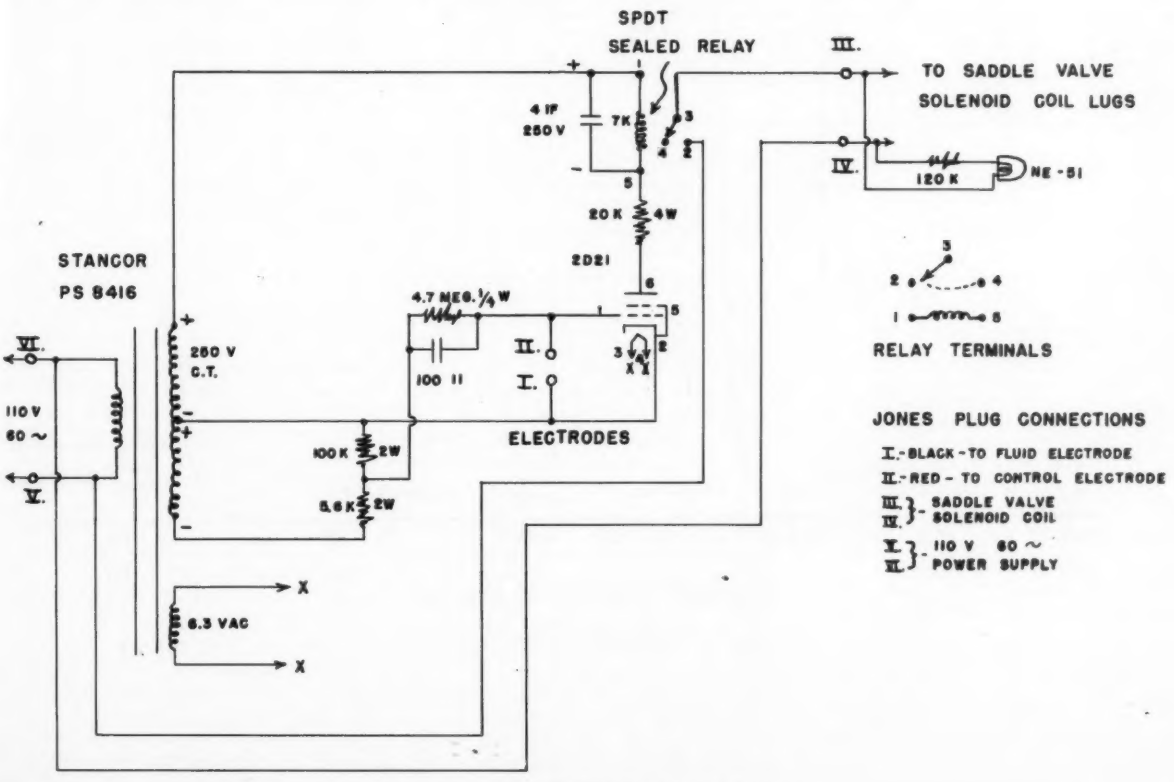

Fig. 6. Liquid level controller for ADAK recorder.

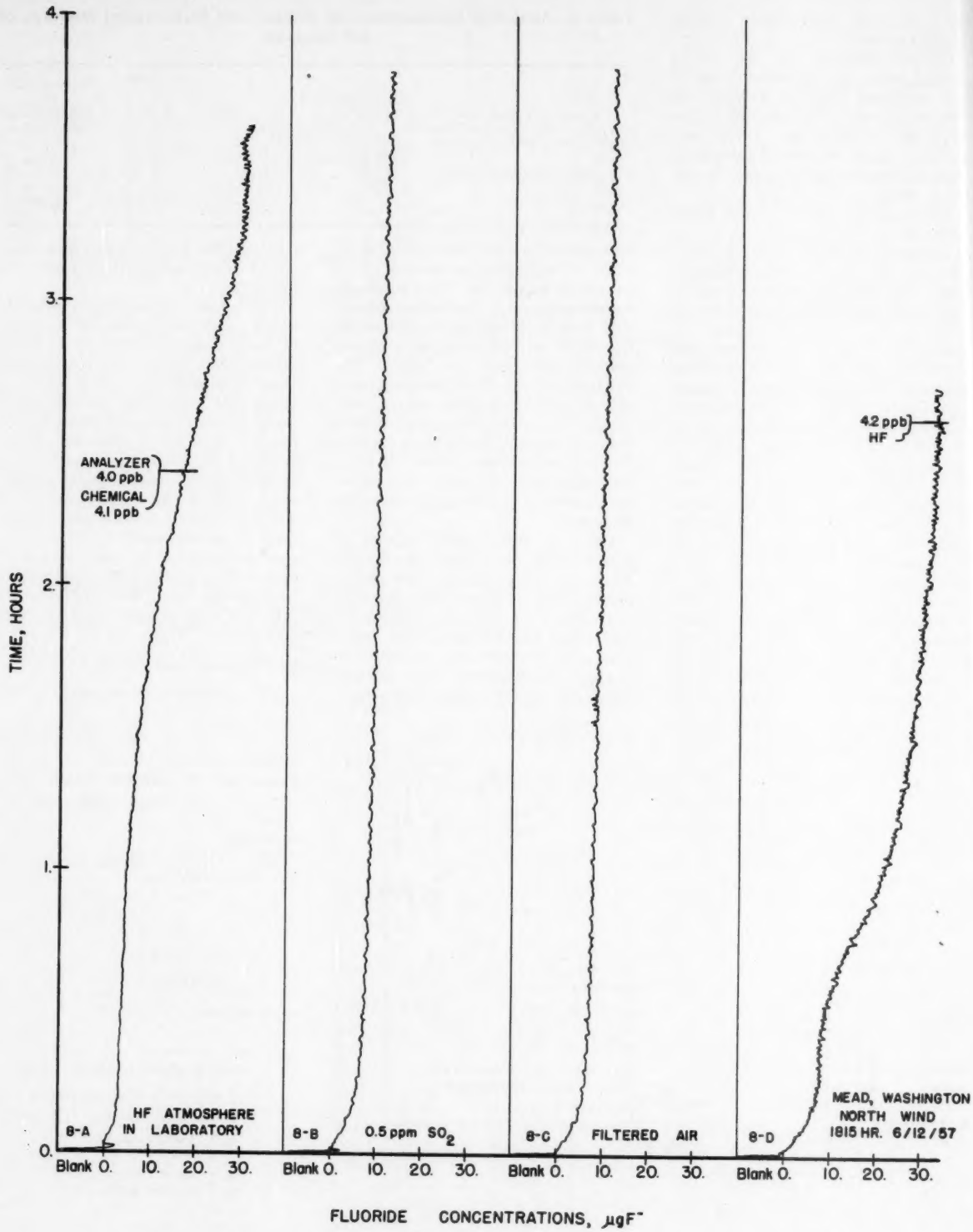

Fig. 8. Typical fluoride concentration records.

ment has been used continuously in field and laboratory studies for a period of five months. Various components of the analyzer were, however, in service up to a total of 18 months during which time the analyzer developed from a manually-operated, laboratory bench model to the final fully automatic assembly. During the field testing program the instrument was mounted in a mobile field laboratory, Fig. 10, and was transported over roads varying in condition from dirt and "washboard" and new construction to concrete pavement. Approximately 1400 mi of roads were covered during the test period. An occasional loose nut or connection was encountered; however, no serious component malfunction resulted from the continuous vibration of transporting the instrument.

The instrumental error involved in the operation of the analyzer was in the order of $\pm 1\%$ T, which is equivalent to ± 1 μg F^- under the conditions of analysis. The major portion of this error was due to variations in the volume of reagent injected into the gas contactor at the beginning of each dosimeter cycle. This error was minimized when the sampling cycle was of short duration. Subsequent models will be designed to eliminate this source of error.

Air was sampled at the rate of 1 cfm and the instrument was adjusted so that the instrument would cycle upon the accumulation of 30 μg of fluoride. A continuous atmospheric concentration of 1 ppb F^- was found to produce a 1% T change in light transmission in a 35 min sampling cycle. Under ideal conditions in the laboratory involving careful control of the reagent volume, it was possible to detect 1 ppb F^- in the test chamber in a 35 min sampling period.

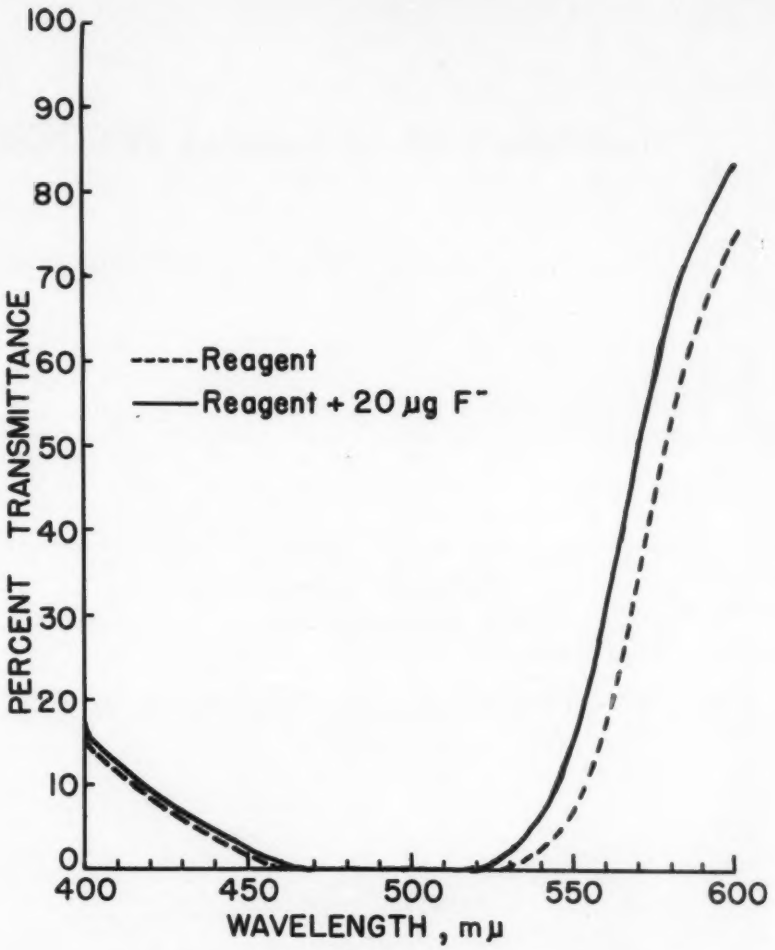

Fig. 7. Spectral Transmittance-modified zirconium-eriochrome cyanine R reagent.

Conclusion

A versatile instrument has been developed which may be used as a dosimeter or a continuously integrating recorder for the automatic analysis of gaseous pollutants for which a colorimetric analytical method may be adapted or devised. Further investigation may indicate that the instrument may be useful in the study of particulate pollutants by pyrolytic pre-treatment of the particulates or utilization of a reagent in which the particulate will dissolve and produce detectable ions. A satisfactory reagent for the determination of atmospheric hydrogen fluoride in a concentration range of parts per billion has been reported. This range of fluoride application may be extended to the analysis of atmospheres of higher concentration such as those found in stack effluents from various industrial processes. This may be accomplished by proportionate reduction of the air sampling rate, thus providing an automatic method for continuously monitoring fluoride emission rates. Similarly, the sensitivity of the instrument and reagent might be increased by successfully increasing the air sampling rate, reducing the volume of circulating reagent and/or application of a reagent embodying greater fluoride sensitivity. Successful field and laboratory tests have been carried out with this analyzer and fluoride reagent.

Acknowledgment

The authors wish to acknowledge the assistance of Lloyd Craine in the design of the electronic liquid level control circuit and the generosity of National Aniline Co., Eastman Chemical Products, Inc., and Air Reduction Chemicals, Inc. in supplying samples of chemicals used in this investigation. They further acknowledge the cooperation of the Bonneville Power Administration and Consolidated Mining and Smelting Co. for furnishing electrical power and field sites used during a portion of the instrument testing program.

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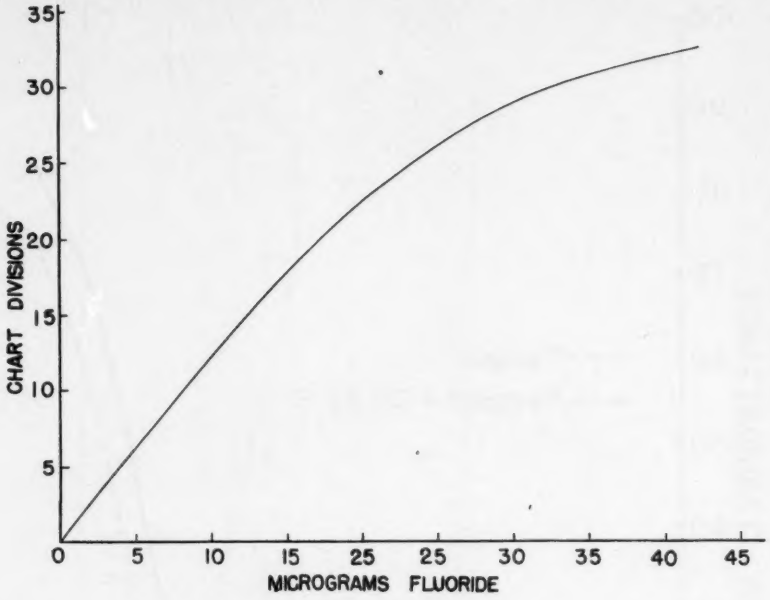

Fig. 9. Fluoride calibration curve.

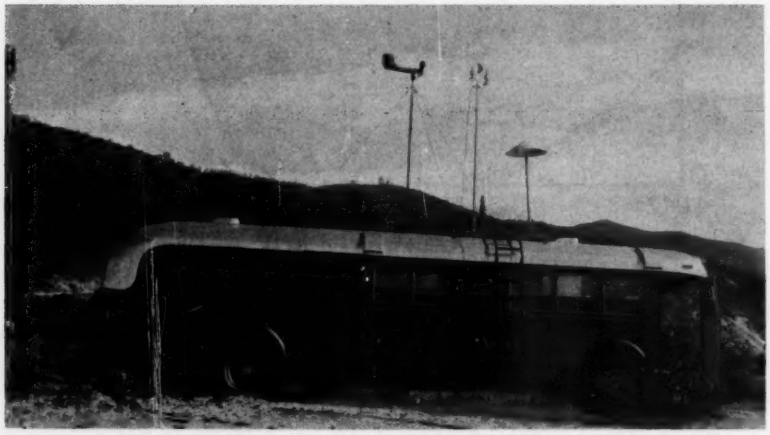

Fig. 10. Mobile air pollution laboratory.

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ABSTRACTS of LEGAL DECISIONS *Relating to Air Pollution*

LEGAL COMMITTEE, E. E. SCHULZE, Chairman, Air Pollution Control Association

***Martin* v. *Reynolds Metals Company*, ——— ———, Ore. ———, 342 P. 2d 790 (Oregon Supreme Court, July, 29, 1959)**

SUMMARY: The deposit upon plaintiffs' land of certain airborne fluoride compounds in the form of invisible gases and particulates emitted by defendant's aluminum reduction plant constituted a direct trespass upon said land and not merely a nuisance.

ACTION: Appeal from a judgment entered upon a directed verdict for plaintiffs for damages arising from trespass, after both parties had moved for a directed verdict.

FACTS: Defendant operated an aluminum reduction plant which emitted certain airborne fluoride compounds in the form of gases and particulates. The gases and particulates, invisible to the naked eye, settled upon plaintiffs' land and allegedly rendered it unfit for raising livestock. Allegedly due to the lack of grazing, undesirable vegetation grew up on the land and caused it to deteriorate further for grazing purposes. Plaintiffs' claim for damages for loss of use of the land for grazing purposes and for deterioration of the land covered the period from August 22, 1951 to January 1, 1956. A fume collection system installed by defendant in 1950 was in operation during the entire aforesaid period. Plaintiffs also alleged that the emissions were careless, wanton and wilful and demanded punitive damages.

TRIAL COURT: After each party had moved for a directed verdict, the court found that plaintiffs had suffered damage in the amount of $71,500 for loss of use of their land and $20,000 for the deterioration of the land and entered judgment accordingly. Plaintiffs' claim for punitive damages was rejected.

HELD: On appeal, the Oregon Supreme Court, one justice specially concurring, affirmed the judgment of the trial court and held:

1. Trespass is any intrusion which invades the possessor's protected interest in exclusive possession of land, whether that intrusion is by visible or invisible pieces of matter or by energy which can be measured only by scientific means.

2. The intrusion of the invisible gases and particulates constituted a trespass, although as an invasion of plaintiffs' interest in the use and enjoyment of the land it could also constitute a nuisance.

3. The six-year statute of limitations applicable to an action for trespass determines the period during which plaintiffs can claim damages and not the two-year statute applicable to nuisance actions.

4. The trial court did not err in refusing to make a special finding requested by defendant to the effect that it was impossible in the operation of an aluminum reduction plant to capture all fluorides which are created in the manufacturing process; that the fume collection system was in operation during the period in question; and that it was the most efficient system known, since the requested finding related only to the claim for punitive damages which was rejected by the trial court.

5. There was substantial evidence from which the trial court could have connected the emanation of the fluorides with the damage alleged.

6. At modern law, however, not every physical intrusion of another's land results in an actionable trespass if the possessor's protected interest is not violated or endangered. (The court attempts to explain at some length the considerations which determine this "protected interest" and whether any particular act constitutes an actionable trespass, citing and attempting to reconcile *Amphitheaters, Inc. v. Portland Meadows* (1948), 184 Ore. 336, 198 P. 2d 847; wherein the court held that the casting of light from defendant's race track upon plaintiff's outdoor motion picture screen, causing diminution of the projected picture, did not constitute an actionable trespass nor a nuisance. The Chief Justice concurred in the *Martin* result, but dissented from the portion of the opinion which attempts to reconcile the present holding with that of the *Amphitheaters* case.)

***Highway 100 Auto Wreckers, Inc.* v. *West Allis*, 92 NW 2d 85 (Wis. Supreme Ct., Apr. 7, 1959)**

ACTION: Declatory judgment seeking the voiding of a regulatory ordinance.

FACTS: Several auto salvage yards were located near a residential district on the highway by-passing Milwaukee. The practice was to burn the automobiles out of doors to dispose of paint, varnish, upholstery, and rubbish, because the steel companies to whom the scrap was sold required uncontaminated compressed bundles of scrap.

STATUTES AND ORDINANCES: Wisconsin statute permitted municipal regulation, licensing, prohibition etc. of any industry "where any nauseous, offensive or unwholesome business may be carried on." Another statute authorized large counties to regulate discharges of smoke, gases, fumes, etc. Milwaukee County had enacted a regulatory ordinance making unlawful the emission of smoke equal to or greater than Ringelmann #2. Pursuant to the act enabling regulation of business, West Allis enacted an ordinance prohibiting the burning of any parts of junked automobiles.

EVIDENCE: Near-by residents testified that the smells incidental to the auto burning were nauseous and offensive, impairing their health and comfort, and that smoke and soot were produced which adversely affected the neighborhood.

TRIAL COURT: Ordinance invalid. The fumes and odors are incidental to the production of smoke and are within the subject matter reserved to the county and covered by its ordinance.

HELD: Reversed.

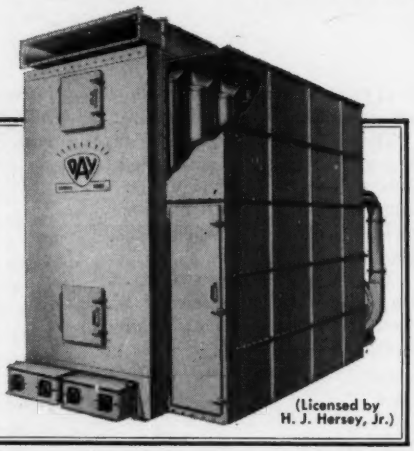
1. Police power extends to public safety, health, morals, and general welfare.

2. Though both smoke and fumes are incidental to the burning of these materials, the county ordinance only regulates smoke, its shade, or density.

3. Except for matters expressly covered by the county ordinance, the

DAY

DUST CONTROL NEWS



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You know all equipment requires *normal* inspection and care. But you'll find many DAY filters have been on the job for 5, 6, 7 or even 8 years that have had no repairs whatsoever. In short, *the Day "AC" is built* to last! They have an "appetite" for work and a reputation for dependability and long life.

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Because of smaller diameter felt filter tubes the DAY "AC" gives you a greater air handling capacity in less space. DAY "AC" filters occupy up to 50% less space — an important consideration for plants of any size!

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city ordinance is not void. It was proper to regulate fumes and odors as long as the county had not done so.

4. Other grounds such as potential fire hazard, set-back requirements made necessary to ease police protection and protection of aesthetics were urged as bases for the ordinance and were approved by the Supreme Court. The trial court had disapproved them.

Addendum

ACTION: Motion for rehearing of case reported at 92 NW 2d 85 (Wis. Supreme Ct., Apr. 7, 1959).

HELD: 1. A section of the Milwaukee County Smoke Ordinance does attempt to regulate noxious gases and fumes, a fact overlooked in the earlier opinion.

2. Regulation of matters covered by the county ordinance is pre-empted, and cities cannot regulate such matters.

3. Court will not rule on constitutional attack based on vague standards concerning smoke emission nor on equal protection of smoke-producing industries, because the ordinance can be sustained as a valid exercise of the police power on the ground that the business regulated is a fire hazard.

Pelletier v. *Transit Mix Concrete Corp.* (174 New York Supp. 2nd 794)

Action by apartment dwellers against operator of nearby ready-mix concrete plant and trucks to enjoin operations during other than normal working hours on ground operation constituted a public nuisance.

Complaint dismissed.

"Congested centers are seldom free from smoke, odors and other pollution from houses, shops and factories, and one who moves into such region cannot hope to find the pure air of the village or outlying district.... Residents of industrial centers must endure without redress a certain amount of annoyance and discomfiture which is incident to life in such a locality "(Bove. vs. Donner-Hanna Coke Corp., 236 App. Div. (N. Y. 37).

"The evidence establishes operation by the defendant with the best and most modern equipment and in conformity with usual custom and proper practice. Effect must also be given to the fact that defendant's plant was in operation prior to the construction and operation of the two (housing) developments and to the character of the neighborhood.

"Whether the use of property to carry on a lawful business which creates smoke, noxious gases, noise or which is offensive to neighbors amounts to a nuisance depends upon the facts of each particular case. (Frank vs. Cossett Cement Products, 197 Miscellaneous (N. Y.) 670)."

(*Continued from page 144*)

a fair picture.

In summary, some of the deficiencies of the type of reporting presented in the present paper may be listed as:

1. Failure to identify major components of the particulate to allow a more reasonable comparison.
2. Disregard of the effect exerted on the samples collected by the wind direction and other meteorological condition.
3. Lack of consideration with respect to the results being indicative of the sampling station only, rather than the entire area covered by the report.
4. The use of city names allows unwarranted comparisons to be made by those who are unfamiliar or ignorant of proper air pollution sampling.
5. Dependence upon a mere set of figures which happen to be within statistical limits of error, rather than a consideration of the factors which would cause variations in the results in the particular area.
6. Failure to explain within the printed text that the method proposed does have these deficiencies, which tends to mislead those who are not so well-informed in sampling techniques.

While there are other deficiencies which have not been touched upon, it must be clearly pointed out that results such as these are bound to carry weight and be given an unwarranted importance, simply because they bear the name of the U. S. Public Health Service.

FEBRUARY

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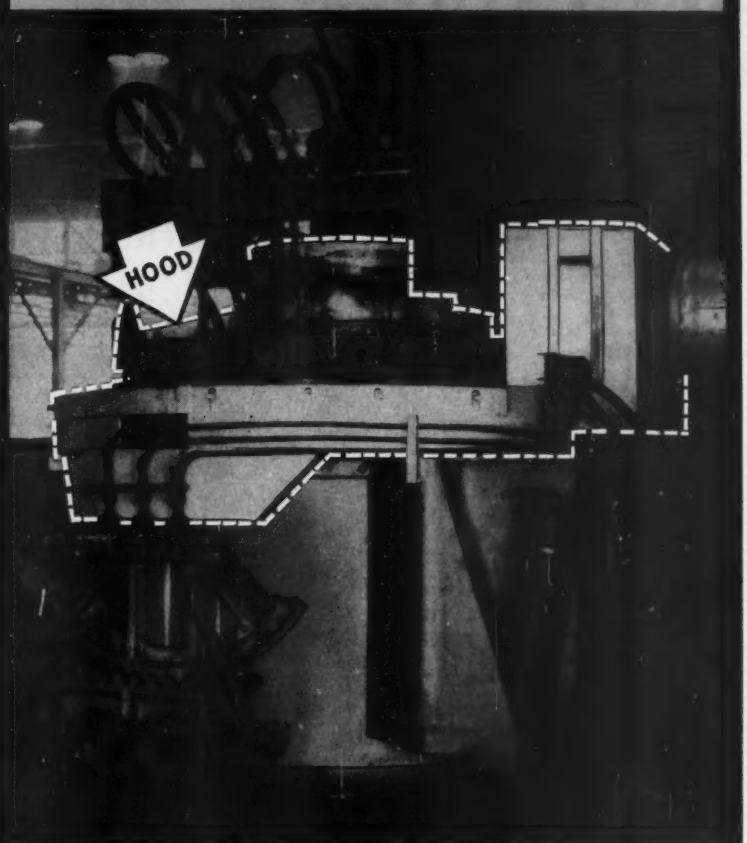

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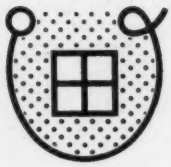

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2. Mailing address.....

3. Individual members: Company, organization, or agency with whom you are affiliated.....
   Company or Sustaining members: Industry affiliation or type of business (steel, petroleum, equipment, etc.)....
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4. Class of Membership (please check)

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Company ☐	50.00
Sustaining ☐	250.00 Minimum

5. Check enclosed herewith ☐
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6. Company or sustaining member's delegated voting representative is:
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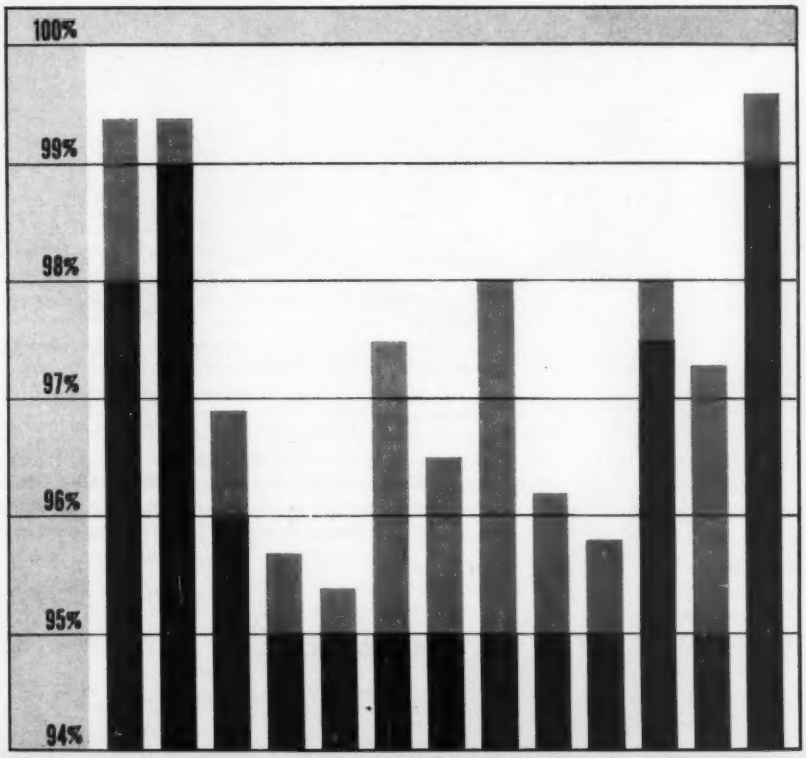
RC 196

Chart shows 13 typical installations which have exceeded guarantees.

(NAMES ON REQUEST)



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